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Advanced Computer Aids in the Planning and Execution of Air Warfare and Ground Strike Operations

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ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Conference Proceedings No.404

ADVANCED COMPUTER AIDS IN THE PLANNING AND EXECUTION OF AIR WARFARE AND GROUND STRIKE OPERATIONS

Papers presented at the 51st Meeting of the Avionics Panels of AGARD held in Kongsberg, Norway 12—16 May 1986.

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THEME

The pace and complexity of modern air warfare are reaching the point where advanced computer aids are becoming essential to assist the air crew in the aircraft and the commander on the ground in performing functions that hitherto had been considered to be their prerogative. This Symposium considered the advances in and practical application of advanced computer aids in terms of its impact on avionic systems design in both manned and unmanned aircraft and weapons systems and on the total air warfare command and control environment including communications, electronic warfare, intelligence gathering and operational planning.

Computers are already used extensively in the operation and control of specific types of equipment, such as advanced weapon systems, surveillance radars, electronic warfare and communications systems. However, in the broader context there are still many areas which rely heavily on human decision making and where the use of computers will have considerable impact in the future.

The increasing use of Artificial Intelligence (AI) techniques, including Intelligent Knowledge Based Systems (IKBS) and Expert Systems will at one extreme allow decision-making to be increasingly automated or controlled by non-expert personnel and at the other extreme greatly extend the capabilities of military commanders by presenting information in a timely manner and by making rapid assessment of alternative strategies. Such facilities become even more important in situations where the personnel are at personal risk. New computer architectures promise to facilitate the processing of even greater quantities of data at high speed through the use of techniques such as parallel processing and networking of systems.

The successful application of computers should provide improved effectiveness, flexibility and reliability of both men and equipment resulting in a saving of resources and personnel. Keywords: artificial intelligence; expert systems; IKBS (Intelligent Knowledge Based Systems)

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La rapidité et la complexité d'une guerre aérienne ont atteint un niveau tel que les Aides-Informatiques de technologie avancée deviennent essentielles pour assister aussi bien les équipages dans leurs avions que le commandement au sol dans l'accomplissement de leurs fonctions, tâches qui jusqu'ici étaient considérées comme ne ressortissant que de leur seules prérogatives.

Ce Symposium a étudié les applications avancées et pratiques des Aides-Informatiques de technologie avancée en termes d'impact sur les concepts des systèmes avioniques pour les avions pilotés ou non et les systèmes d'armes dans l'environnement global d'un commandement et de contrôle de guerre aérienne comprenant: les communications, la guerre électronique, le recueil des renseignements et les plans des opérations.

Les ordinateurs sont dès maintenant utilisés dans la mise en oeuvre et le contrôle de types d'équipements spécifiques tels que: Systèmes d'armes avancées, Surveillance radar, Systèmes de guerre électronique et de communications. Cependant dans un contexte plus élargi, il y a encore beaucoup de domaines qui dépendent encore étroitement des prises de décisions humaines et où l'utilisation des ordinateurs aura un impact considérable dans l'avenir.

L'accroissement de l'emploi des techniques relatives à l'Intelligence Artificielle incluant les systèmes basés sur la connaissance de l'intelligence et les systèmes experts pourront d'une part, permettre une automatisation accrue des prises de décisions ou d'être mieux contrôlées par un personnel non spécialisé, et d'autre part, d'étendre largement les possibilités du commandement militaire par la présentation de manière opportune et dans les évaluations sur l'alternative stratégique.

De telles facilités deviennent encore plus importantes quand les situations où le personnel est un personnel à risque. Les architectures des nouveaux ordinateurs permettront de faciliter le traitement et la qualité des données, à grande vitesse, par l'usage de techniques telles que le traitement en parallèle et le maillage des systèmes.

Le succès de l'emploi des ordinateurs devrait fournir une amélioration de l'efficacité et de la flexibilité à la fois de l'homme et de l'équipement; ce qui aurait pour résultat l'économie des ressources et du personnel.

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CONTENTS

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Reference

SESSION IV – HARDWARE

SESSION V – SENSOR INTEGRATION

EXPERT SYSTEMS

SESSION VI – PLANNING AND CONTROL

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THE USE OF KNOWLEDGE BASED SYSTEMS TECHNIQUES IN ESM PROCESSING

by

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SUMMARY

The Electronic Support Measures (ESM) System attempts to detect, analyse and classify sources of radio and radar emissions in the environment. The ESM system provides valuable emitter classification information to the host platform's Command and Control System or associated Electronic Countermeasures (ECM) equipment. However, the current generation of Automatic ESM systems often produce ambiguous or incorrect emitter classifications in the adverse conditions of actual conflict. This paper describes the application of Knowledge Based Systems techniques to ESM processing and outlines the development and evaluation of a Knowledge Based ESM system model aimed specifically at improving the emitter classification capability of automatic ESM.

1 GLOSSARY OF TERMS

C^2	Command and Control
CEF	Current Emitter File
CW	Continuous Wave
DF	Direction Finding
ECM	Electronic Countermeasures
ESM	Electronic Support Measures
EW	Electronic Warfare
EWSG	Electronic Warfare Scenario Generator
EWRM	Electronic Warfare Receiver Model
GHz	Giga-Hertz (10^9 Hz)
KB-ESM	Knowledge Based Electronic Support Measures
KBS	Knowledge Based System
KS	Knowledge Source
PRI	Pulse Repetition Interval
PW	Pulse Width
RF	Radio Frequency
TOA	Time of Arrival

2 ELECTRONIC SUPPORT MEASURES

2.1 The Electronic Support Measures (ESM) system is concerned with the detection, analysis and classification of radio and radar signals. ESM provides details of the signal environment either to the host platform's Command and Control System, for use in tactical situation assessment or to an integrated Electronic Countermeasures (ECM) system. This paper will be restricted to the discussion of Radar ESM, although the techniques described in subsequent sections will be generally applicable to radio frequency ESM systems.

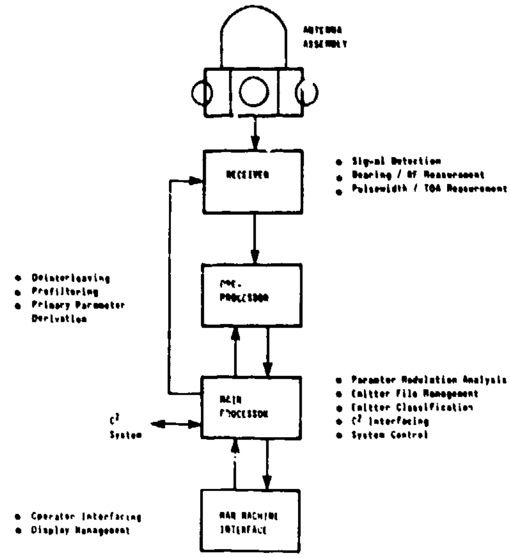

FIGURE 1 ESM SYSTEM BLOCK DIAGRAM

2.2 The block diagram of a typical Automatic ESM System is presented in Figure 1. The system is composed of the following subsystems.

- the Antenna and Receiver
- the Preprocessor
- the Main Processor
- the Man-Machine Interface

2.3 The Antenna and Receiver must be capable of detection of all radar frequencies used by own forces, neutral and enemy radar sets. The typical frequency coverage is 2-18 GHz although extensions to cover the millimetric wavelengths above 18 GHz are becoming of increased importance. Similarly the sub-system must be able to detect signals arriving at all azimuth angles around the host platform. The receiving unit detects incident signals (above system sensitivity) and measures the signal characteristics. The characteristics of a typical pulsed radar signal that are measures by the receiver are:

- Angle of Arrival (bearing)
- Carrier Frequency
- Pulse Width
- Amplitude
- Time of Arrival

2.4 However, since the receiver will detect and measure each incident pulse in chronological order, the receiver output will require sorting to reconstruct pulse chains from the individual emitters in the environment. This sorting process is carried out by the Pre-processing element of the system, and is termed 'De-interleaving'. The aim of the de-interleaving function is to produce just one pulse chain for each detectable emitter in the environment, although this is seldom possible in practice.

2.5 The Pre-processor element also acts as a data rate reduction mechanism to ensure that the main processor can cope with its pulse chain analysis, classification and sytem control tasks. In addition, the Pre-processor removes all unwanted pulse data (e.g. from high duty rate emitters) that had previously been analysed and classified by the system to further reduce the mainprocessor load.

2.6 Each pulse chain derived by the de-interleaver is either associated with a current entry, or creates a new entry in the Current Emitter File (CEF). Subsequent analysis of the interpulse modulation of the RF, PRI, PW and Scan parameters are stored against this CEF entry.

2.7 The CEF maintenance algorithms attempt to solve the problems created by the de-interleaver and in particular the reconstruction process is based largely upon parameter matching techniques - that is pulse chains are combined with existing CEF entries if their parameters meet some form of matching criteria.

2.8 The Modulation Analysis Functions within Automatic ESM attempt to augment the basic pulse chain

parameters produced by the de-interleaver (i.e. bearing, RF range etc.) with details of how the pulse parameters vary over the detected pulse chain. The Radio Frequency, Pulse Repetition Interval and Pulse width parameters are often analysed by the compilation of parameter occurence histograms. These are subsequently interpreted to give the modulation details of the particular parameter.

2.9 The amplitude modulation of a pulse chain can be analysed to produce an indication of the periodicity and antenna scan pattern of the target radar. This information yields important extra information for use in the classification process, and the function is termed Scan Analysis.

2.10 The emitter classification function is accomplished by comparing the parameters of a particular CEF entry with each record in a library of known emitter characteristics. This library contains parametric details of all radar emitters within the system's frequency coverage that are likely to be encountered in a particular operational situation.

2.11 The library comparison process results in a candidate set of emitter records from the library which match the CEF entry. This candidate set is then subjected to confidence assessment which produces a measure of the accuracy with which the CEF entry parameters match those of the library entry. This confidence indicates the likelihood of each candidate emitter type corresponding to the particular CEF entry.

2.12 ESM systems can be used in a variety of different roles in a conflict situation, including:

a) SELF PROTECTION - in association with 'hard kill' (e.g. ship to ship missile systems) or 'soft kill' (e.g. Electronic Countermeasures) systems, the ESM equipment can help protect the host platform against radar-assisted attack.

b) TACTICAL SITUATION ASSESSMENT - since the ESM system provides emitter classification data, it is obviously complementary to primary radar (which measures range and bearing of targets) in the assessment of the host platform's tactical environment.

c) EARLY WARNING - it is often possible to detect targets at long ranges from the host platform using ESM, even outside the primary radar's coverage. It is also possible in certain situations to detect, analyse and classify radars over the conditions by exploiting Anomalous Propagation (ANAPROP) conditions.

It is therefore obvious that ESM must be capable of deriving high quality emitter classifications to fulfill these important roles and to be fully effective.

2.13 However, Automatic ESM systems are required to operate in a number of adverse conditions which makes the successful classification of emitters difficult. These adverse conditions include.

- the very high pulse data rates that may be detected by a sensitive ESM system in postulated conflict scenarios.
- the trend towards usage of radars exhibiting complex modulation strategies, which make the ESM systems deinterleaving and analysis tasks difficult.
- the presence of noise jamming in the environment, which adversely effects certain receiver types.
- the presence of high powered 'friendly' radars in the vicinity of the ESM system which can seriously impede certain aspects of system performance.

2.14 Moreover, the structure of the current generation of Automatic ESM systems implies that errors arising at the receiving stages due to these adverse operational conditions are propagated through the de-interleaving and modulation analysis elements. As a direct consequence of this error propagation, the classification function often produces highly ambiguous (i.e. several possible emitter classifications are presented) or in the limit erroneous results.

3 KNOWLEDGE BASED ESM SYSTEM DEVELOPMENT

3.1 To directly address the emitter classification problem described in the last section, and with the overall aim of improving ESM system effectiveness, Software Sciences Ltd embarked on a privately-funded Knowledge Based ESM System (KB-ESM) development programme.

3.2 The aims of this development were several fold, namely

- to improve the overall performance of automatic ESM by optimising the processing subsystem
- to apply novel hardware and software architectures to achieve this optimal processing
- to assess the improvement that KBS techniques could offer in the classification of radar emitters,
- to develop a comprehensive ESM System Evaluation facility using a suite of modelling programs.

3.3 During the initial phases of this development, a comprehensive survey of the types of Knowledge Based System (KBS) which could be used in ESM processing was undertaken. As a result of this survey, the Blackboard Architecture was chosen because of its flexibility and suitability to the complex time varying signal analysis problems of ESM. The Blackboard Architecture was originally developed for use in speech understanding and has subsequently been used for a variety of applications including Sonar Classification and Sensor Data Fusion.

3.4 There are three components of the Blackboard Architecture:-

- the Blackboard
- knowledge sources, and
- the scheduler

The Blackboard is a structured global data base which may be subdivided into levels, panels and entries as shown in figure 2a appropriate to the particular application. The levels usually represent 'levels of abstraction', where the lowest level represents, for example, raw data gathered from a transducer or sensor and the highest levels represent high confidence information deduced from the lower levels. Several different types of entry may exist at each level.

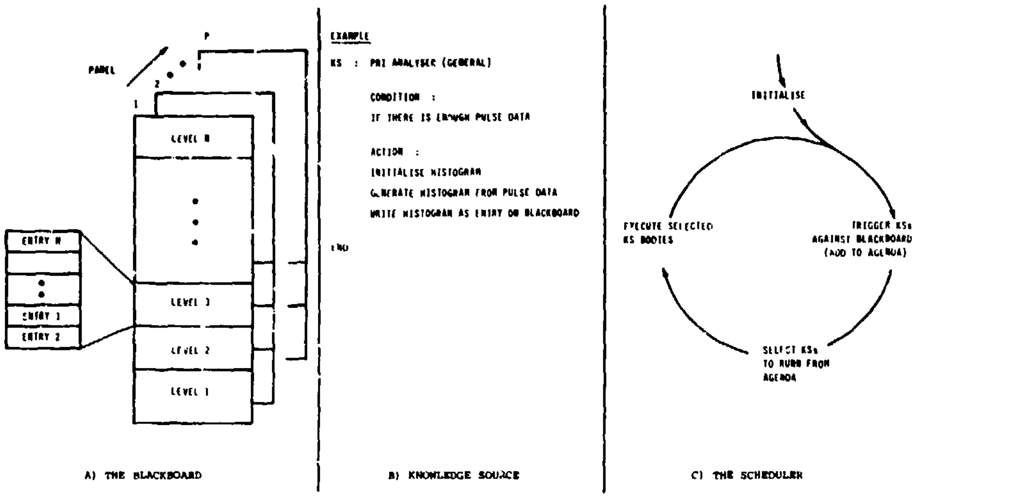

FIGURE 2 BLACKBOARD ELEMENTS

3.5 The Knowledge Sources manipulate, create or consume entries on the Blackboard based upon procedures (algorithmic) or declarative (rule-based) knowledge. An example knowledge source (KS) is shown in Figure 2b. Each KS has a condition part and an action. If the condition part (which refers to entries on the Blackboard) evaluates to be true, then the KS becomes a candidate for activation and as such is placed on an Agenda. If it is activated, its action part will run causing modification to the Blackboard contents.

3.6 The selection of a KS from the Agenda to run is performed by the scheduler, the action of which is shown in Figure 2c. The way in which the scheduler selects the KS from the Agenda on any particular cycle of operation is totally adaptive and in general would also depend on the contents of the blackboard.

3.7 The main features offered by a Blackboard approach as applied to ESM processing are:

- the support of the hypothesis and Test paradigm, whereby initial emitter classification hypotheses are formed and subsequently validated or disproven by the application of special purpose analysis techniques to the pulse chain data.

- the capability to alter the processing priorities adopted within the system according to the current situation, in contrast to the rigid priorities imposed by the more conventional system.

- the ability to allow the system to choose one of several pulse chain analysis algorithms according to the circumstances, for example, special purpose modulation analysis techniques are used to make use of 'a-priori' information of previously detected emitter types or as part of the hypothesis testing process.

3.8 To make full use of these features, a Knowledge Based ESM system model was developed to prove the functionality of the Blackboard approach and to gather performance metrics for use in optimisation of the KB-ESM system towards real time operational usage. The KB-ESM system model incorporates all necessary features of the ESM processing system, including.

- A de-interleaver which is under the full control of the Blackboard mechanisms.

- RF, PRI and PW modulation analysis algorithms.

- Emitter Classification algorithms (including library access and hypothesis and test)

- Special purpose display formats

- Adaptive system control and scheduling

3.9 The KB-ESM system model runs on a VAX 11 series computer under a Knowledge Based System development environment called POPLOG. The development and subsequent assessment carried out to date has shown that within a controlled evaluation environment, the KB-ESM system model is able to produce consistent unambiguous emitter classification results.

3.10 Much of the improved classification capability is due to the application of the hypothesis and test technique. The emitter hypotheses are formed by accessing the emitter library with coarse but reliable pulse chain parameters in much the same way as current generation systems. Each candidate emitter is then subjected to a verification process using distinguishing features of the emitter retrieved from the library record. This information is used as the basis for the 'a-priori' analysis of the pulse chain in question to prove or disprove the existence of the candidate emitter. Only emitter classifications validated in this way are presented to the operator as correct classifications hence decreasing the probability of erroneous or ambiguous results. This process is illustrated in Figure 3.

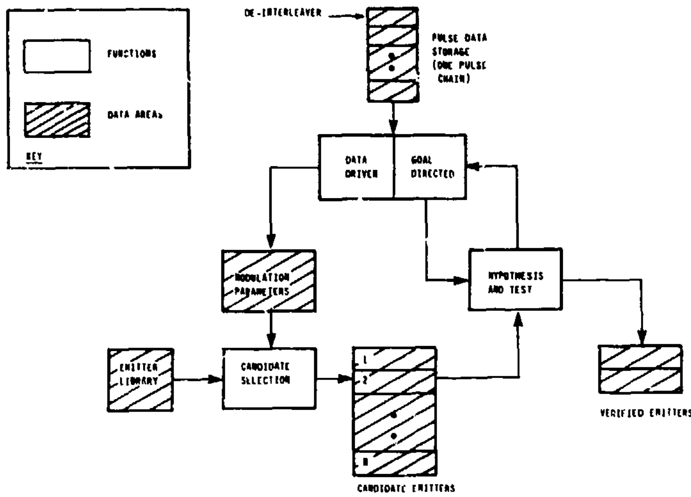

FIGURE 3 HYPOTHESIS AND TEST TECHNIQUE

3.11 In addition to providing reliable classification of a correctly de-interleaved pulse chain, the evaluation of the KB-ESM system model has proven its capability to classify several separate emitters which are initially placed into a single pulse chain due to their close parametric proximity. Furthermore, the KB-ESM system model can successfully recombine split pulse chains from a wide band frequency hopping radar by extending the hypothesis and test technique back to a second (rule-based) de-interleaving stage.

The KB-ESM System model was developed with a set of displays to allow the operator to

- oversee the system operation, using the tabular emitter summary displays common in automatic ESM.

- monitor the hypothesis and test function from candidate emitter set generation through emitter verification using special purpose display formats.

- monitor the modulation analysis of a particular pulse chain using special purpose graphical display options.

The strictly hierarchic nature of these displays ensures that the system defaults to fully automatic mode, with summary displays available for this purpose. However, the 'lower level' display options can be invoked to allow the skilled operator to monitor the detailed system operation.

4 KB-ESM SYSTEM EVALUATION

4.1 In order to assess fully the capabilities and limitations of the KB-ESM System Model, a comprehensive evaluation programme was undertaken following system development. Since an incremental and controlled assessment technique was essential to this evaluation programme, a modelling approach was adopted throughout. This will be followed in the near future by the development and assessment of a prototype trials system.

4.2 A block diagram of the assessment facility used to evaluate the KB-ESM system model is presented in Figure 4. The evaluation process consisted of the generation of test scenarios of various complexities from which the signal environment at the ESM receiver could be simulated. The performance of the ESM receiving element was subsequently modelled and the receiver output used to evaluate the KB-ESM.

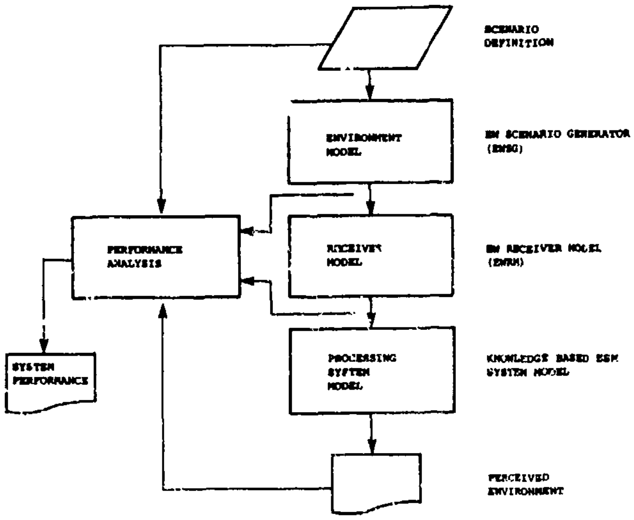

Figure 4 EVALUATION SYSTEM

4.3 The Environmental Modelling function was accomplished using the Software Sciences EW Scenario Generator (EWSG) program. EWSG allowed the operational Scenario to be defined in terms of the relevant platforms (airborne, shipborne or landbased), their position and their radar fits. The characteristics of the radar fits were subsequently used to generate an electromagnetic environment (i.e. pulsed, CW and jamming signals) as incident at a user specified sensor position. The operational scenario was dynamic in that full platform motion was modelled throughout the simulation including platform manoeuvres in course, speed, altitude, roll, pitch and yaw at predefined simulation times. The simulated signals were of a highly sophisticated nature to represent postulated modulation agility schemes and scan strategies.

4.4 The subsequent Receiver Modelling function was accomplished using the Software Sciences EW Receiver Modelling (EWRM) program which allowed the user to model either

- Channelised Receiver,
- an Instantaneous Frequency Measurement Receiver,
- a Swept Superhet Receiver or
- a Multiport Bearing receiver

The antenna system was fully defined in terms of:

- its polar diagram in the Azimuth and Elevation planes
- the variation of this polar diagram with RF

4.5 Furthermore, suitable interpolation routines were provided to calculate the antenna gain in a general (i.e. non planar) direction and at any pulse frequency.

4.6 Similarly, the Direction Finding and RF receiver element characteristics such as:

- Sensitivity (as a function of RF)
- Dynamic Range
- Bandwidth
- Dead time (due to recovery effects)
- Simultaneous Signal Capability
- ECM resistance

were simulated, as were the principle sources of parameter measuremnt error within the particular receiver type. The output of the receiver model was subsequently used in the controlled evaluation of the KB-ESM.

4.7 Since the assessment of the KB-ESM system model was accomplished in controlled conditions generated by an environmental model, it was possible to assess automatically the performance of the receiving and processing subsystems. This was possible since pulse data generated by the Environment Model was 'tagged' with a source emitter identification field. This field was compared with the ESM system's perception of the emitter type to give an assessment of system performance.

5 CONCLUSIONS

5.1 The development and subsequent thorough evaluation of the Knowledge Based ESM system model has proven that the application of the Blackboard Architecture and particularly the hypothesis and test method can produce unambiguous emitter classification results. Further, evaluation in scenarios depicting adverse operational conditions for ESM has shown that the techniques are particularly useful in these situations.

5.2 To summarise, the application of the novel software architecture has optimised the effectiveness of automatic ESM and hence the overall aims of the development programme were attained.

5.3 The KB-ESM research programme continues, however, aimed primarily at producing an operational ESM system using the techniques described in this paper. The other main areas of research activity are

- the extension of the Blackboard Architecture to control the ESM receiver and hence produce optimal receiver response to augment the emitter classification process.
- the extension of the KB-ESM system model to incorporate emitter association and platform classification at the ESM system as part of the hypothesis and test process.
- the use of special purpose display formats and interfaces to allow operator interaction with the KB-ESM system.

These extensions to the KB-ESM system will further improve the effectiveness of automatic ESM by optimisation of the processing elements.

DISCUSSION

R. Voles, UK
What, roughly, is the typical scale ratio between the rate at which the modelling is performed and real-time?

B. Jackson
Currently the KB-ESM system is written in POP-11 which is run on a timeshared VAX 11-750. When a typical complex EW scenario is simulated the system has been found to run at a rate which is approximately 1000 times slower than real-time. Performance measurements have shown that over 90% of this time is spent in the embedded de-interleaver. This would normally be implemented on a separate high-performance dedicated chip.

Evaluation has shown that the techniques developed are capable of real-time implementation and Software Sciences' current work is in the enhancement of the real-time applicability of the techniques developed. We see this as the adoption of the beneficial aspects of the KB-ESM but implementation in Ada. The Ada implementation will encode the rules as interpretted data structures so as to maintain some of the flexibility of the knowledge based approach.

J. Whalley, UK
Could you briefly describe the POP-11 environment and the problems you have experienced.

B. Jackson
The POP-11 environment used is the POPLOG system originally developed by Sussex University. This runs on a VAX 11-750 under the VMS operating system. This language has been found to be very good at fast prototyping of knowledge based applications in the ESM domain. The limitations encountered have been in terms of speed of execution, overall machine resources consumed, effect on other users of the time shared system and more significantly the program size limitations encountered. The KB-ESM system has grown in complexity during its development phase and has now reached the physical limitations imposed by the POP-11 system. Some further enhancement would be possible if we restructured the existing program to make more efficient use of the available system facilities. It is felt that this would only provide a short term breathing space.

R.W. MacPherson, Canada
Could you comment on the applicability of your techniques to the identification of emitters other than radar?

B. Jackson
The techniques developed have been specifically aimed at the problems encountered in conventional ESM systems. The techniques and approach adopted are directly applicable to other Signal Analysis problems. Software Sciences have already investigated applicability of this approach to the SONAR problem and we believe that the techniques are also applicable to other similar areas. The techniques of emitter association and platform classification developed recently as part of the KB-ESM, but not covered in this paper, are also more widely applicable in the area of multi-sensor data fusion.

R.S. Dale, UK
How does the system react to emitters which are not in the emitter library?

B. Jackson
When an emitter is encountered that cannot be matched against any existing library entry the system is unable to generate a verified hypothesis concerning the identity of the emitter. As such the system states that it is unable to reach verified status and tells the operator that it has detected a previously unknown emitter. This is an improvement on existing systems which frequently inform the operator of an incorrect identification when an exact match cannot be made. The KB-ESM system having concluded that the detected emitter is previously unknown can provide facilities to enable the operator to create an "invalidated" library entry. This entry records the detected parameters of the new emitter and can provide various recording facilities to enable further analysis on return from the current mission.

H. Timmers, Netherlands
How are the input data generated? Are they assembled from real life, or are they generated artificially?
How do you deal with uncertainty in the data?

B. Jackson
The input data has been generated using two of Software Sciences' EW simulation and modelling packages EWSG & EWRM. EWSG is a general purpose Radar environment scenario generator that is capable of producing digitally uncoded pulse data for up to 99,999 different emitters each of which can be fully defined in terms of electromagnetic radiation properties and positional movement. EWRM is a package which enables the realistic modelling of all common ESM receiver types with the ability to fully specify the receiver characteristics using a high level interpretive English like language. The scenarios modelled using these facilities were defined and agreed in conjunction with the UK MoD, RAF and HSRE to be truly representative of certain predicted threat situations. The KB-ESM system deals with uncertainty in the data by the use of the knowledge based techniques described in the paper. The extensive evaluation exercise that was undertaken was centred around predefined situations which cause uncertain and ambiguous classification in the current generation of ESM systems. The KB-ESM system was proven to be significantly better than existing systems at deriving unambiguous and correct interpretation of small quantities of "uncertain data".

AD-P005 426

DARPA's AirLand Battle Management Program and USAF's Tactical Expert Mission PLAnneR (TEMPLAR)

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SUMMARY: The Defense Advanced Research Projects Agency (DARPA) has a long history of supporting research in the area of Artificial Intelligence (AI). DARPA's Strategic Computing Program is developing an AI technology base upon which several applications programs are being built including the AirLand Battle Management Program (ALBM). The ALBM program office is cofunding the US Air Force's first major AI application: Rome Air Development Center's Tactical Expert Mission PLAnneR (TEMPLAR). TEMPLAR is an advanced development level effort that is building upon demonstrated systems at the exploratory development level as well as the Strategic Computing tech base. This paper describes the TEMPLAR program and its links to the AirLand Battle Management and Strategic Computing Programs.

INTRODUCTION

Since its creation in 1958, the Defense Advanced Research Projects Agency (DARPA) has been a major benefactor to basic research in computer science in the United States. A major portion of the early research in Artificial Intelligence was supported by DARPA in the 1960's. DARPA has continued in the 1980's to promote and develop promising computer technologies with the Strategic Computing Program.

In late 1983 the Strategic Computing Program (SCP) was announced. The program was organized to develop machine intelligence technology at many different but complementary levels [1]. This was done to take advantage of the many advances that have reached maturity in recent years. Figure 1 [2] shows the program structure as a pyramid where the base represents microelectronics technology and each additional level builds from the previous. Near the top of the pyramid are the application areas: Autonomous Systems, Pilot's Associate, and Battle Management. Each of the areas contains one or more major application program.

One of the application programs under the Battle Management area is the AirLand Battle Management (ALBM) Program for which the US Army is the lead Service. The ALBM program's namesake, AirLand Battle, is a new concept that has been incorporated into US Army doctrine. Originally called AirLand Battle 2000, this evolutionary doctrine emphasizes, among other things, closer cooperation between air and land forces. Thus it is fitting that this predominately US Army program has US Air Force participation.

The ALBM Program Office is cofunding the US Air Force's first major AI application program with Rome Air Development Center (RADC). That program is RADC's Tactical Expert Mission PLAnneR (TEMPLAR). The technical objective of TEMPLAR is to move and apply demonstrated AI to a military planning problem. The operational or domain objective is to design, build, test and evaluate a decision aid to assist USAF planners in generating the daily Air Tasking Order (ATO) i.e. to assist in solving a resource allocation problem. The remainder of this paper will discuss the TEMPLAR program as it relates to the Strategic Computing Program, the AirLand Battle Management Program, and the future of Artificial Intelligence based planning in military systems.

In order to discuss TEMPLAR's relationship to these DARPA programs we must first present background information on the program and the problem area it addresses. The following section discusses the history of the technical foundation upon which TEMPLAR is being built. The next section discusses the scope of the program, in particular, how the research goals of this advanced development program are different from those of the earlier exploratory development programs. Finally, before the ties to the DARPA programs are discussed, a short discussion of the problem area is presented.

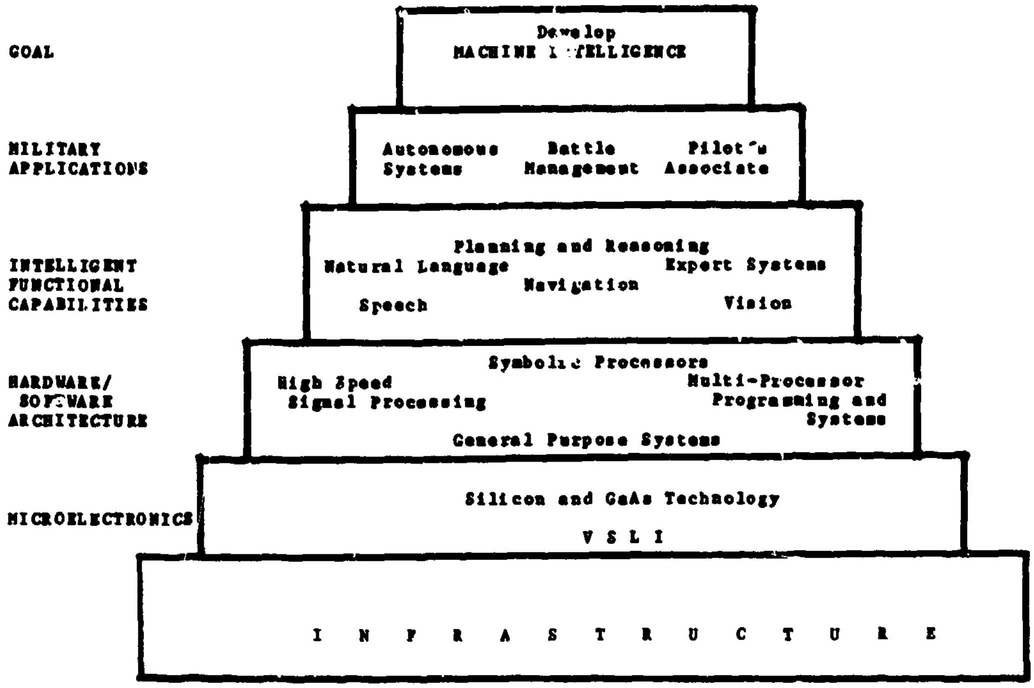


Figure 1
Strategic Computing Program Structure

TEMPLAR Program History

The roots of TEMPLAR began in the late 1970's with the Knowledge Based System (KNOBS) program under Dr. Carl Engleman at the MITRE Corp., Bedford MA. Early support for this effort came from the Air Force Office of Scientific Research (AFOSR), DARPA, and RADC with later support coming fully from RADC. An objective of this exploratory development program was to show if or how AI techniques could be applied to a resource allocation planning problem. This effort dealt with only one portion of the ATO generation problem: tasking for Offensive Counter Air (OCA) missions. KNOBS successfully demonstrated that AI techniques are applicable but is notable more for its integrated use of several knowledge representations: production rules, frames, frame-based constraints, and natural language usage.

TEMPLAR is building upon this technology as well as that from the KNOBS Replanning System (KRS), the preliminary TEMPLAR design, and extensive work on Man Machine Interface (MMI) issues done by the Air Force Human Resources Laboratory (AFHRL) at Wright-Patterson AFB, OH. After a six month effort on the preliminary design, the present TEMPLAR program was defined with respect to cost, scope, and schedule. The resulting competitive procurement ended with an award in September 1985 to TRW Systems Engineering and Development Division, Redondo Beach , CA.

TEMPLAR Scope and Research Emphasis

The main task of the TEMPLAR Advanced Development Model (ADM) will be to assist planners in generating an entire ATO. The earlier efforts planned only one mission type and only one mission at a time. TEMPLAR must deal with the whole spectrum of mission types; figure 2 [3] lists the mission types and gives a brief description of each. TEMPLAR must also allow multiple planners to work in parallel. This raises the issue of distributed processing. Thus the scope of the problem domain is greatly expanded over earlier efforts.

In addition to the change of scope, there is a change of research emphasis when moving from exploratory development to advanced development. The TEMPLAR ADM must be "near operationally robust." This entails several requirements. First more realistic data will be used in the data- and knowledge-bases. Second the Man Machine Interface (MMI) must be built with the planning process and operational environment in mind. Close interaction and frequent feedback will be needed to ensure that TEMPLAR is usable by field level personnel. Third since the ADM is not intended to actually be fielded the following issues need not be addressed: militarized, TEMPEST, or ruggedized hardware; power, weight, and transportability requirements; operational security and maintenance.

Another result of requiring the system to be "near-operational" is that an operational scenario will be used to test and evaluate the final ADM. Rather than try to build a system generic enough for all of the tactical air forces, TEMPLAR is targeted at one of them in particular. Experience has shown that many "generic" systems prove to be only marginally useful to most and very useful to none. A CENTAF scenario was chosen, in part, because of CENTAF's strong interest in getting more automation. [CENTAF is the AF component of USCENTCOM, the unified command whose area of interest is South West Asia and the Middle East. CENTAF's major peace time constituent is USAF's 9th AF.]

CAS - (Preplanned) Close Air Support: missions against targets that are in the immediate range of the battlefield; most CAS is not preplanned.

OCA - Offensive Counter Air: includes missions that degrade the enemy's capability to generate sorties and establish air superiority; offensive in nature, thus airfields, radar systems, etc are common targets.

DCA - Defensive Counter Air: as above a type of Counter Air but reactive to enemy's initiative; includes Air Defense, Escort, and Combat Air Patrol (CAP).

AI/BAI - Air Interdiction / Battlefield Air Interdiction: includes missions that destroy enemy resources before they can be brought to bear on the battlefield; the difference between the two is related to the distance from battle lines and the amount of coordination required between air and land forces.

RECCE - Reconnaissance: includes missions that gather intelligence data before and after other destructive missions.

Tanker: a type of support mission but listed separately because of its importance to the CENTAF domain; where, when, how much, and to whom fuel is off-loaded is specified in th ATO.

Mission Support: includes missions for electronic warfare and defense suppression.

Figure 2
Mission Types

Air Tasking Order Generation

The Air Tasking Order (ATO) is a document that tasks the air resources of all subordinate units on a daily basis. The tasking is done by the Combat Plans division of a Tactical Air Control Center (TACC) (or its equivalent). The TACC is a theater level organization and yet the tasking is quite detailed and specific. Everything from the time over target to where aerial refueling will take place is specified; figure 3 lists the items which are specified for each mission. In order to best use the available airpower many relationships between tasking items must be considered. A simple example is the relationship between aircraft and weapons load (they must be compatible). A more complex example is the relationship between missions which use the same refueling resource but which have different targets and objectives.

Target	Aircraft	Ordinance (Weapons load)
PD (Probability of destruction)	No of Aircraft	Refueling Service
TOT (Time over target)	Airbase	Call Sign
TD (Time of departure)	Unit (Wing or Squadron)	Transponder
		Frequency

Figure 3
Items specified in an ATO

Presently ATO generation is a lengthy and manpower intensive process. The planning time is on the order of 12 hours and the intelligence data used may be as old as 36 hours. Over 50 people are required by the Combat Plans division to generate an ATO. There are two aspects of ATO generation that can be improved by computer automation. The first is the mechanics of the process and the second is the higher level decision process. TEMPLAR will help with both aspects. TEMPLAR could reduce the time by a factor of three (3) to six (6) and manpower requirements by four (4) to ten (10).

TEMPLAR and the Strategic Computing Program

One strong link between TEMPLAR and the Strategic Computing Program (SCP), irregardless of programmatic ties, is the technology. Both are AI programs instead of programs that use AI. As mentioned above the SCP is addressing a wide range of areas spanning the spectrum from hardware to software and from AI program management to system development environments. In fact due to the broad scope of the program it has often been described as the US response to Japan's Fifth Generation Program. With reference to the SCP's pyramid structure (figure 1) half of the six technology areas identified in the level labeled "Intelligent Functional Capabilities" are relevant to TEMPLAR. Those three areas are Expert Systems, Planning and Reasoning, and Natural Language.

The use of Expert Systems, and Planning and Reasoning technologies is evident in more than just TEMPLAR's name. The system will assist planners by checking relevant constraints, offering suggestions, planning details left unspecified by the user, and explaining its own reasoning. TEMPLAR will not be just a rule based expert system. The technology baseline systems, KNOBS and KRS, do use rules but also use heirarchical frames (a la Marvin Minsky) and frame based constraints. TEMPLAR will also use these knowledge representations. Thus reasoning may be based on inheritance, constraints, rules, or a combination thereof.

TEMPLAR is also using Natural Language technology. The Natural Language interface will be one of three ways to interact with the system. In addition to using a menu mode or a graphics mode, users will be able to interact with typewritten English sentences. These sentences need not always be complete or grammatically correct as long as they are in context, i.e. the system must be able to handle ellipsis and anaphora. Figure 4 gives examples of both ellipsis and anaphora.

CONTEXT	TEMPLAR: ... User: Does Ramstein have any F-15s? TEMPLAR: Yes, Ramstein has 24 F-15 aircraft.	
CURRENT	User: Does Hahn? (Ellipsis)	User: Are they ready to take off? (Anaphora)
INTERPRETATION	--> Does Hahn have any F-15s?	--> Are the F-15s ready to take off?

Figure 4
Examples of Ellipsis and Anaphora

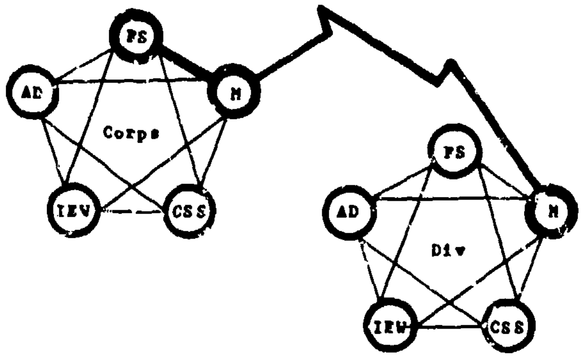
TEMPLAR and the AirLand Battle Management Program

The AirLand Battle Management Program (ALBM) was initiated at DARPA in FY 1984 and the Joint DARPA/US Army program was established in June 1985 [4]. Thus the ALBM joined the US Navy's Carrier Battle Group System program in the Battle Management application area of the SCP. In September 1985 an industry briefing was held on the ALBM background and objectives. This section looks at the links and similarities between the ALBM and TEMPLAR.

The ALBM briefing stressed several ideas about how AI and Expert Systems technology should be used in the AirLand Battle environment. The briefing mentioned that previous Expert Systems (ES) have matured in the hands of users. Therefore, the ALBM requires interaction between the development contractors and US Army personnel. In particular, two service schools, at Forts Leavenworth and Sill, will be involved in the knowledge acquisition and engineering.

TEMPLAR is also involving operational users. Representatives from HQ TAC and 9th AF (CENTAF) have participated in proposal evaluations and various program review meetings. Wider representation to include 12th AF, USAFE, and PACAF is expected at the Design Plan review (Mar 86) and the Functional Description review (Oct 86). Also, there was extensive user involvement and feedback in the design of AFHRL's Tactical Air Operations Team Training System (TAOTTS) which is being incorporated into TEMPLAR.

The ALBM program structures Army operations into five functional categories; they are Maneuver, Fire Support, Air Defense, Intel/Electronic Warfare, and Combat Service Support. Two of the functional areas, Maneuver and Fire Support are considered representative and especially important. The ALBM requires two expert systems called MOVES(C) and FIRES(C) to be built for Corps level operations and one called MOVES(D) for Division level; figure 5 [4] shows the relationship between the required ESs. The three separate ESs must communicate with one another demonstrating both horizontal (Corps to Corps) and vertical (Corps to Division) interaction.



M - Maneuver

FS - Fire Support

AD - Air Defense

IEW - Intel/Electronic Warfare

CSS - Combat Service Support

Figure 5
ALBM Program Structure

In addition to the individual communicating expert systems, the ALBM program requires that a customized system expansion tool called STAR be built. STAR would allow additional communicating ESs to be easily built for the remaining functional areas at both Corps and Division level.

TEMPLAR is not nearly as ambitious in this regard, but does support the use of AI system building tools. One of the TRW team contractors is Carnegie Federal Systems of Carnegie Group, Inc. (CGI), Pittsburgh PA. CGI has developed two commercially available AI tools: Knowledge Craft(TM) and Language Craft(TM). Knowledge Craft is a set of tools or building blocks for creating ESs. You are not required to use a certain set of AI paradigms, for example, forward chaining plus production rules plus an inference net. Thus it is not an ES shell, but an ES development environment. Language Craft is a set of tools that allows a grammar writer to easily create a customized Natural Language (NL) interface. It is not as generic as Knowledge Craft, i.e. it does not allow different NL processing paradigms. Language Craft is based on the case frame instantiation approach.

A final link between the ALBM and TEMPLAR to be discussed is the similarity of the problem areas. The Army has the OPORD or Operations Order, while the Air Force has the ATO. Both orders task subordinate units based on guidance from higher levels, both must consider the constraints or relationships between component actions, and both are lengthy and manpower intensive processes. Due to this similarity, one of the two formal demonstrations of TEMPLAR will be a part of the ALBM Phase II demonstrations at Fort Leavenworth, Kansas, in the fall of 1987.

The Future for (Naturally and Artificially Intelligent) Military Planners

The future for military planners with natural intelligence is promising. There will be more time for the high level decisions on strategies and tactics with less time spent on mundane bookkeeping and number crunching details. The added flexibility will allow increasingly sophisticated and complex planning to be done. TEMPLAR technology will allow more efficient and effective use of resources and thus better application of tactical airpower.

The future for planners with artificial intelligence is also promising. A successful TEMPLAR ADM will clarify what areas need additional research and what capabilities can be fully automated. A follow-on system will be well defined and ready for insertion of the latest advances. These advances may be from the Strategic Computing tech base (e.g. the Compact LISP Machine hardware), from lessons learned in the AirLand Battle Management program, or from ongoing research in replanning (or real time planning) at RADC e.g. AMPS (A Metalevel Planning System).

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[3] USAF Air Ground Operations School, BATTLE STAFF COURSE BOOK, Oct 85

[4] Defense Advanced Research Projects Agency, "AirLand Battle Management Program Briefing to Industry", 18 Sep 85

DISCUSSION

R. Voles, UK
You have said that the natural language input to TEMPLAR is "free form". But some constraints must exist. Could you kindly say what they are.

P.F.H. Priest
Most queries made in the system within the mission planning domain are correctly understood on the first attempt. Very few queries need to be restated more than twice.

S.C. Boehmer, USA
What hardware does TEMPLAR use and what hardware will be used for BLUE FLAG?

P.F.H. Priest
Symbolic 3670 or 3640.

R.J. Scott-Wilson, UK
What optimization is carried out on the plans produced and what criteria are employed for such optimization?

P.F.H. Priest
Each individual mission is optimized to provide a plan which is consistent with the constraints that the user provide for that particular mission. There is no global optimization. AMPS, a follow on effort to KRS, will deal with this problem.

KRS: A Knowledge-Based Mission Planner

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ABSTRACT

KRS is a knowledge-based system for planning offensive-counter-air missions. KRS aides human planners in preparing Air Tasking Orders. KRS can either be used interactively as a plan verifier or autonomously as a plan generator. KRS informs the user of any logical or doctrinal inconsistencies in a plan, and keeps track of resources and target status. Users can communicate with KRS via a natural language interface, pop-up menus, or a mouse pointing device. This paper presents an overview of KRS's capabilities, its knowledge representation schemes, how KRS verifies plans, and how plans are automatically generated.

INTRODUCTION

KRS (Knowledge-based Replanning System) is a state-of-the-art mission planning system that helps a human planner create and manage multiple offensive-counter-air missions by verifying plan consistency and tracking resource availability and usage. KRS makes heavy use of Artificial Intelligence tecnniques, is programmed in LISP, and runs on a Symbolics Lisp Machine.

KRS is the result of over twenty man years of research and development in the application of artificial intelligence technology to the planning domain. KRS has been developed by the MITRE Corporation in Bedford, Massachusetts, for USAF's Rome Air Development Center. It should be emphasized that KRS is a research project aimed at exploring the issues involved in automated and semi-automated mission planning, and is not a product ready for use in the field. The goal of this paper is to describe KRS's capabilities, how they are used, and how they work.

WHAT KRS DOES

In its current operating scenario, KRS is located at an Allied Tactical Operations Center (ATOC) in Europe and is used to aid mission planners in the production of Air Tasking Orders (ATOs). KRS is limited to planning Offensive-Counter-Air (OCA) missions and their associated support missions: refueling, air escort, and Surface-to-Air Missile (SAM) suppression.

KRS is properly thought of as a "partner" in the mission planning process. KRS can be used interactively by the user as a data base and a plan verifier, or it can automatically generate ATOs with minimal human input. As a data base, KRS knows about resource availability and allocation, target defense status, and weather conditions. KRS can also be used to access facts about different aircraft, ordnance, and target types. In its plan verification role, KRS checks to make sure a mission plan is logically consistent (e.g. the aircraft to be used are available at the base to be used) and does not violate current airwar doctrine. The interactive and autoplanning modes of KRS can be freely mixed -- a user can plan as much of the mission as desired and automatically plan the rest. Conversely, if a user does not like the plan generated automatically by KRS, the plan can be modified interactively until it is acceptable to the user.

KRS has a sophisticated multi-media user interface that utilizes natural language, windows, a "mouse" pointing device, and color graphics. The user is free to mix the form of input in any way. The natural language subsystem is based upon conceptual dependancy and scripts [PAZZ83a, PAZZ83b]. Natural language can be used to query the data base ("Where is the longest runway located?") or to direct the planning of a mission ("Hit X's runway with 3 F-111E aircraft"). KRS has a vocabulary of about 100 words and is capable of handling anaphoric references and some ungrammatical input. KRS uses scripts to help guide the user through a mission plan by asking questions. The user can choose to ignore KRS's attempt at a dialogue and plan the mission in whatever order he wishes.

Figure 1 shows a typical KRS display. The window in the front right, labelled OCA1003 is an actual offensive-counter-air mission plan. The area labelled B has the "slots" composing the plan. Each slot is a piece of information about the plan. Each OCA mission has 13 slots: target, probability of destruction, aircraft, unit, airbase, ordnance, number of aircraft, time of departure, time over target, refueling, call sign, frequency, and transponder. (The last three slots are

generated automatically by KRS and are not supplied by the user.) OCA1003 is shown after planning was initiated by typing "Hit Merseburg's runway with 3 F-111E" at the KRS top-level window. As you can see, KRS was able to fill several plan slots from this sentence: Merseburg's runway is the target, F-111E is the aircraft, and 3 is the number of aircraft.

Figure 2 shows how KRS informs the user of plan conflicts. The user has asked for a listing of all the airbases, and then has told KRS to use Hahn Air Base. In KRS's data base there are no F-111E's at Hahn, so KRS highlights the conflicting values in inverse video. In this example, both the aircraft slot value, F-111E, and the airbase slot value, Hahn, are highlighted. A message is also printed out explaining that Hahn does not have any F-111E aircraft. The user can either delete the value for one of the conflicting slots, or can specify another value for the slot. When the conflict is resolved the highlighting disappears. Conflicts are the results of constraint violations, which will be discussed later. This conflict could have been avoided by asking KRS to list the airbases acceptable for this mission, and only airbases that had at least 3 F-111E's would have been listed; Hahn would not have been one of them. Listing the acceptable values for a slot is called "enumeration" in KRS jargon. When KRS is asked to enumerate the acceptable values for a slot, it takes into account all the information it knows about the current plan. If you are attacking a runway with F-111E's and ask about ordnance possibilities, KRS only suggest those ordnances which are suitable for runways and that are carried by an F-111E. If you were using F-4C's, KRS would suggest a different list of ordnances.

The mouse may also be used to fill in slot values. The user places the mouse cursor on a plan slot and clicks a button on the mouse corresponding to "add value." A small window pops up and the user types in the value for the slot. In general, anything the user can do with the keyboard can also be done via the mouse, and vice versa.

Slots have several other mouseable options besides "add value": they can be enumerated, ordered, and explained via the mouse. Enumerating a slot lists the possible legal values for a slot. Ordering a slot is more useful than enumerating -- KRS ranks the choices and suggests which choice would be best. Not every slot can be enumerated or ordered; the plan slots that deal with time, for example. Ordering is done by sorting the enumerated values according to a rating function. For example, the rating function used for ordering ordnance choices is the single aircraft probability of destruction using each ordnance.

KRS also uses high resolution color graphics to display geographic data. As the user plans a mission the target, airbase, and refueling orbits are displayed. The user can also plan missions by mousing on targets and bases displayed on the graphics display. Target and airbase information can be displayed using english commands such as "show all the long-track radars" or "show all the West German bases." One display particularly useful for planning shows the surface-to-air missile sites (and their threat radii) which defend a given target.

The data base in KRS can be updated to reflect changes in the state of the world. Intelligence reports can be entered to inform KRS of changes in force status, enemy SAM activity, and weather conditions. If any plans KRS knows about are invalidated by these changes, KRS informs the user. KRS can either make suggestions about replanning or replan the missions to avoid new conflicts if possible.

One more noteworthy feature in the KRS user interface is the ability of a planner to restrict the values of certain plan slots. For example, KRS might be told to strike a target between 0800 hours and 1030 hours, or to use either Hahn or Sembach as the airbase. Conversely, the user can also tell KRS not to use Hahn or Sembach. The number of values that a slot may be restricted to is not limited to two; any number of the possible values for a slot may be restricted.

Most of the preceding discussion dealt with planning offensive-counter-air missions, but all of the discussion can be generalized to include planning support missions. KRS provides a framework, called a package, for integrating an OCA with its support missions. Each package can be given a priority by the user. This priority is used to determine which missions get critical resources if there is not enough to go around.

HOW KRS WORKS

Internally, KRS uses five different forms of knowledge representation: the dictionary, frames, templates, constraints, and rules. Understanding how each representation is used and how it is related to the other representations gives a broad overview of how KRS works. Each of the knowledge representations will be discussed separately.

The dictionary stores word meanings and senses used by the conceptual dependancy parser. The parser provides KRS with a limited capability for understanding natural language input. Currently the dictionary contains about 100 words. The user can easily add synonyms to words already in the dictionary. With more effort it is possible to define adjectives that refer to some attribute slot of a frame.

Frames are used to represent objects, such as aircraft or enemy search radars. Frames store values for named attributes of an object in slots. For example, if an object has a length and you wished to know its value, you would look in the LENGTH slot of the object's frame. There are two important properties of frames that make them particularly useful as a knowledge representation scheme: first, a frame can "inherit" knowledge from a more general frame; second, frame slots can have "deamons" associated with them. A deamon is a piece of procedural code that is attached to a slot that is run whenever the value of a slot is changed or accessed. Deamons can provide information about how to fill a slot if it is empty, default values, and side effects when accessing a slot.

Inheritance allows information to be organized in a hierarchical fashion. For example, a frame describing generic fighter aircraft has slots which capture general information about fighters. A frame describing an F-15 can incorporate the generic fighter frame, allowing the F-15 frame to capture information unique to the F-15 without having to duplicate the information stored in the generic frame. These two frames can refer to each other via slots called AKO (A Kind Of) and INSTANCES. For example, the generic fighter frame could have its INSTANCES slot contain pointers to F-4, F-15, and F-16 frames, and each of these aircraft frames could have their AKO slot point back to the generic fighter frame. If a frame is asked for a slot value it doesn't know, it looks to its parent, the frame in the AKO slot, for the value. If the parent doesn't know, it asks its parent, and so on until the slot value in question is found.

The natural language subsystem interfaces with frame representations in order to answer user queries. The interface matches up a query's semantic representation (the output of the parser) with a suitable inferencing procedure. KRS has a wide variety of inferencing procedures available for answering common questions. For example, if the user asks "How many F-4C's are at Hahn?", several actions are performed by an inferencing procedure to answer this question. KRS first looks in the frame for Hahn air base and finds the fighter units assigned to Hahn. Each unit is asked if it is composed of F-4C's. If so, then KRS asks how many F-4C's are assigned to the unit. KRS then totals up the number of F-4C's, tells the user the total number, and gives a breakdown by unit.

Templates are a specialized form of frame. A template acts as a guide for autoplanning and verifying missions. Each type of mission (OCA, refuel, etc.) has a template telling what plan slots are needed for the mission and how to go about filling them. The templates also contain the constraints that apply to each plan slot.

The fourth form of knowledge representation in KRS is constraints. Constraints are procedures that enforce relationships between plan slot values. For example, one simple constraint checks to make sure that if aircraft X is to be used from airbase Y, that X is actually available at airbase Y. If not, then a conflict is signalled. Constraints deal with the physical relationships; they verify the hardware chosen for the mission is available at the right places at the right times and can perform the necessary tasks. Constraints are not only used to verify user specified slot values, but also to generate legal values for slots. Constraints are used as value generators when the user asks KRS to enumerate the possible values for a given plan slot, and by the autoplanning mechanisms.

The KRS constraint mechanism is quite complex. A constraint cannot be checked unless all the plan slots involved in the constraint have been given values. If a constraint cannot be run because all the plan slots involved do not have values, it is put "on hold", and run whenever the values become available. The frame deamon facility is used to coordinate and manage the checking of constraints. The writers of KRS have given a great deal of thought to what a user should be told when constraint violations occur. If more than one violation occurs, should the user be told about all of the violations? For example, suppose a mission plan has target X and uses F-111E aircraft. The user tells KRS to use Mildenhall as the airbase. It turns out that two conflicts are violated: the distance to target X from Mildenhall is beyond the range of an F-111E, and there are no F-111E's at Mildenhall. Each constraint has a certain priority associated with it, which is used to determine what information is most important for the user to know. In this particular case, only the latter reason for rejecting Mildenhall is presented to the user. A more detailed discussion of how the KRS constraint system works can be found in [MILL85].

KRS employs both forward and backward chaining rules as forms of knowledge representation. The backward chaining rules deal mostly with doctrinal issues, and the forward chaining rules deal with force status changes and intelligence reports. Rules are used in a way similar to constraints, with the added advantage of being directly accessible to the planner and can be changed while KRS is running. KRS provides a rule editor that can translate the rules from LISP into english and also translates user-supplied changes from english into LISP. When a rule-based constraint is violated, the user can query KRS as to why the violation occurred. KRS allows the user to examine the data and rules leading to the violation.

The autoplanning mechanism integrates most of the knowledge representation schemes. When KRS is told to autoplan a mission, it first looks to the mission's template for guidance. The template specifies the order in which the plan slots should try to be filled. KRS enumerates the possible values for each slot, and chooses one value. KRS then tries to fill in the next slot. When a choice causes a constraint violation, the violated constraint provides KRS with information about which plan slots should be changed in order to make the violation go away. This search method is known as dependency-directed backtracking. KRS keeps filling in plan slots until the plan is complete. If KRS is given a partial plan and told to complete it, KRS will not change the values assigned by the user. If a complete plan is not possible for the given partial plan, KRS is usually able to tell the user why a complete plan is not possible. The user can then change the partial plan and resubmit it for completion.

From the paragraph above, it might already be obvious that KRS returns the first complete plan it finds that does not violate any constraints. KRS makes no attempt to "optimize" plans in any way. An optimal plan is very difficult to produce (either by man or machine), because there is no set definition for plan optimality. Optimality is a quality that varies with different situations. On one day a plan may be optimal if it uses as few sorties as possible; on another day a plan may be best if it guarantees total destruction of a target at any cost; another day the safest mission might be optimal. Because of these considerations, KRS avoids trying to optimize plans.

If KRS doesn't optimize planning across many missions, what is it good for? KRS excels at planning complete, valid plans quickly. (These examples will give you an idea of KRS's speed. KRS can autoplan a mission against a single target that will require aerial refueling on both ingress and egress in less than one minute, including planning and coordinating the refueling flights. Airbase X has four missions (2 aircraft each) scheduled for departure at 0900. Airbase X is attacked at 0730 and will be out of commission until around 1300. KRS is notified that X is down; it automatically finds other bases with the resources for X's scheduled missions and replans the missions using the other bases. Whenever possible, these new missions will have the same time over target and refueling rendezvous as the original missions. Three minutes after KRS is notified of airbase X going down, it has finished rescheduling X's missions.) What KRS provides is greater flexibility to try out several different plan alternatives before making a final choice.

KRS's FUTURE

As was stated at the beginning of this paper, KRS is only a research tool. It was designed to be a proof of concept demonstration, not a field-ready product. The ideas and technology developed during the KRS project is being applied by MITRE in building AMPS (A Meta-Level Planning System). AMPS will explore issues such as plan optimization, the use of global strategies in the metalevel control of planning, and dynamic replanning. Rome Air Development Center is also working to bring artificially intelligent mission planning capabilities closer to deployment in the field with TEMPLAR (Tactical Experimental Mission PLAnneR). TEMPLAR is a prototype system for planning a wide variety of tactical air missions, not just OCA's. TEMPLAR is scheduled to be tested at the USAF Blue Flag exercise in late 1987.

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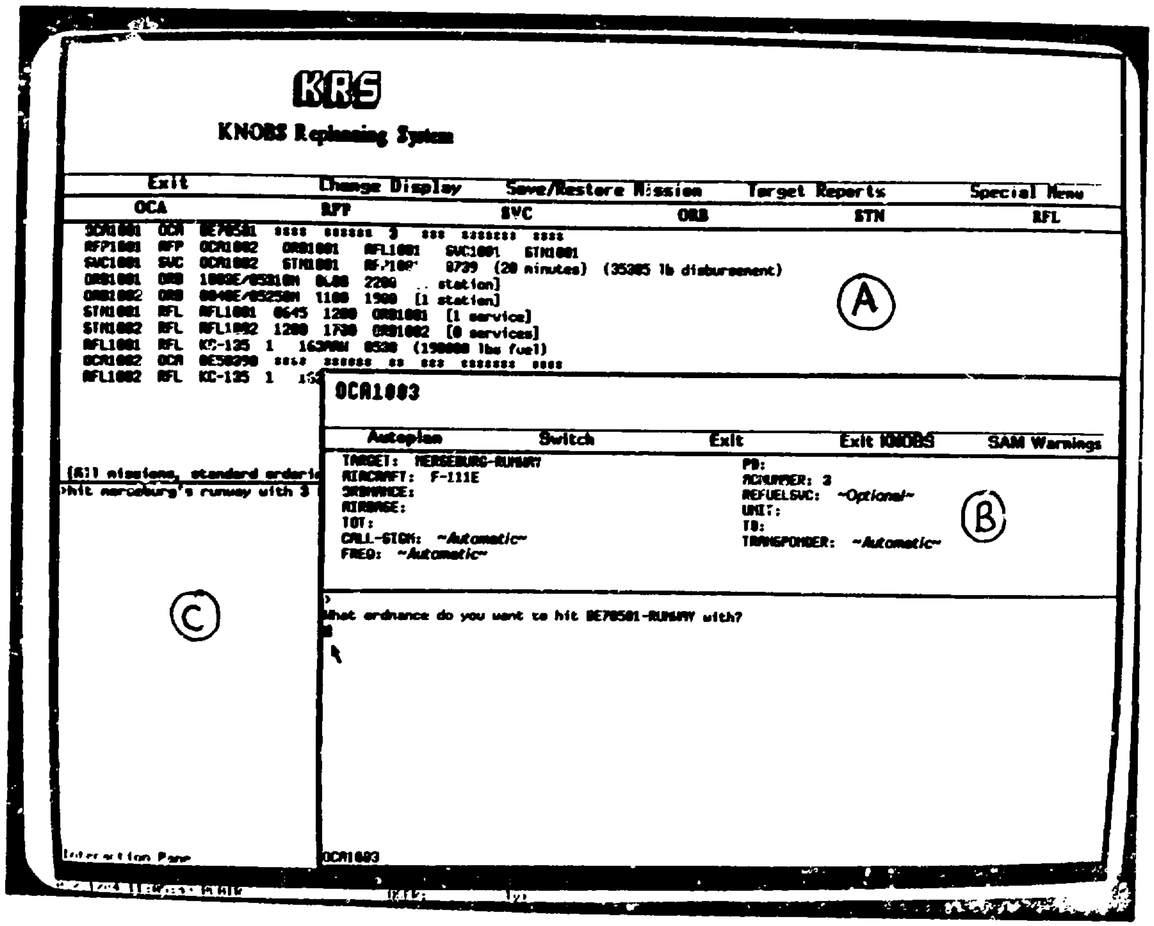

<u>Figure 1</u> (A) table of contents of all missions planned by KRS, (B) a partially completed OCA mission, (C) window for natural language interface.

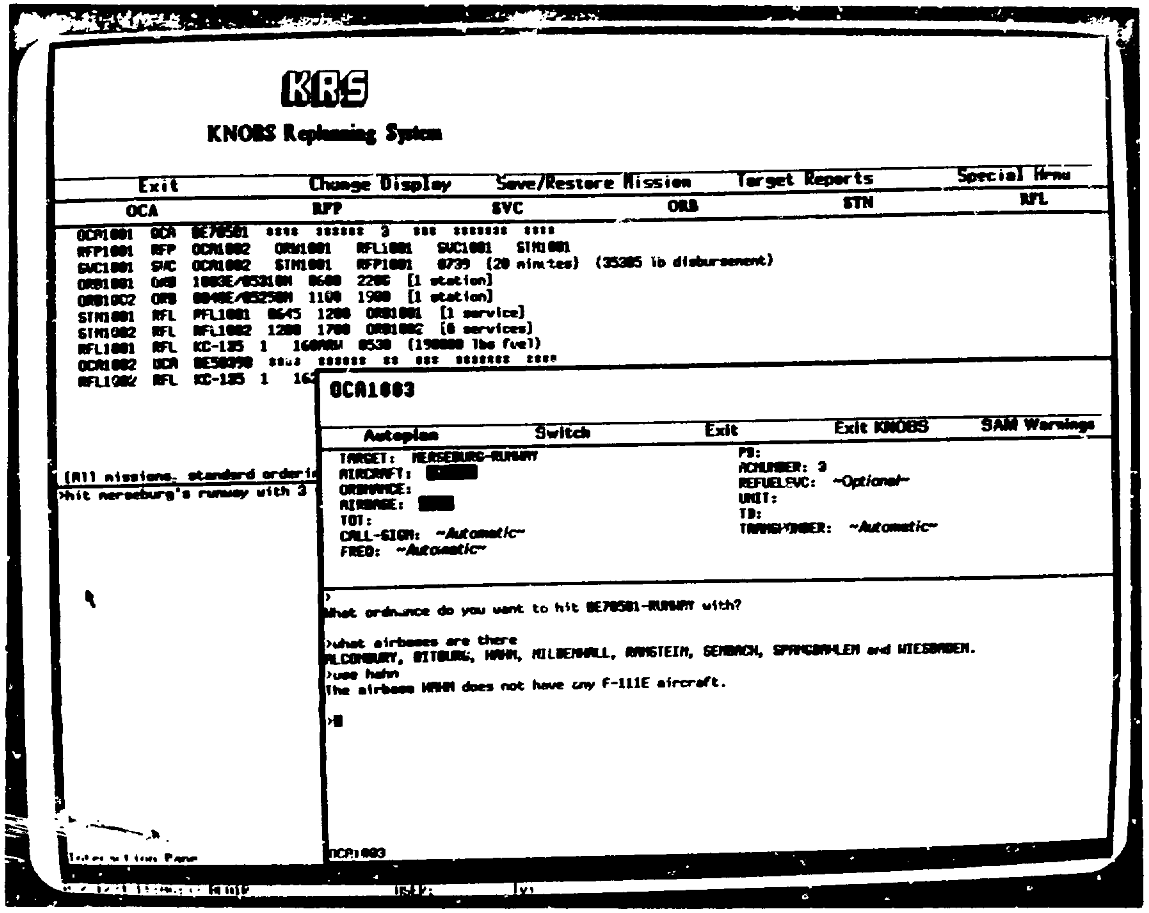

Figure 2 An example of how KRS indicates that there has been a plan conflict. The values in conflict are highlighted. Notice the natural language dialogue.

DISCUSSION

W.E. Howell, USA
What is the relative time comparisons between the KRS mission planner and a "manual" process for the same mission?

K.M. Benner
Planning a single mission with KRS takes about 1 minute. Planning 10 packages of several OCA missions and supporting mission, takes approximately 10 - 15 minutes with KRS. Replanning with KRS takes approximately 4 - 10 minutes depending upon how many missions had to be replanned. Planning of these same missions by people alone takes approximately 2 - 5 times longer. There are cases where it takes even longer.

J. Schmitz, Netherlands
In planning for an OCA mission, can KRS put together a force package, assemble it within the current airspace constraints and plan for its routing I.A.W. the current airspace control orders to avoid fratricide?

K.M. Benner
KRS can put together a package of OCA, Air Escort, Sam Suppression, and refuelling co-ordination all in time only. KRS does not attempt to deal with the problems of fratricide or air space control.

R.J. Scott-Wilson, UK
In both papers, you have read today, you have stressed the use of natural language input. In your experience, do operators use this facility, or do they quickly transfer to the mouse and menu input systems to improve speed?

K.M. Benner
Yes. To the trained person, mouse and menu are always faster. This is still true even if we assume a perfect natural language interface. Natural language is good for naive users or as an intermediate step to speech understanding.

P. Sommaro, Italy
Preparing the missions package. Does the system take into account attrition parameters?

K.M. Benner
No. Attrition rates were accounted for when deciding how many sorties could be flown that day.

AD-P005 428

DECISION AID FOR THREAT PENETRATION ANALYSIS

by
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SUMMARY: The purpose of this paper is to describe a concept for a threat penetration analysis decision aid. A proof-of-concept version of this aid has been built ~~at RADC~~ on a Symbolics 3670 Lisp processing system. Route planning aids have been created in the past to find a path through an area of ground threats. Unfortunately these aids tend to be limited by a narrow perspective of the threat environment and a mathematical approach that makes it difficult to add features. The intent of this effort was to create an aid that used heuristic reasoning to simplify the analysis and which had a more global perspective of the environment than the existing aids. Although there has been recent work, most notably a TPW effort for in-flight replanning, that offers a more global perspective of the environment than existing aids, the approach used in this aid is unique. The concept presented here offers great increases in speed over present route planning aids at a slight loss of precision. In addition, the aid goes beyond simple route optimization and can grow to directly assist in choosing tactics, Electronic Warfare application, or saturation techniques. It also can quickly add, delete, modify or move threats. It can take on these additional tasks by exploiting its speed advantage and data structure. This paper will describe the basic architecture of the aid, some of its limitations, its advantages, its growth potential, and finally some recommendations for application development and further research.

1. BACKGROUND:

RADC has undertaken a major effort in the area of decision aid development. As part of this effort, RADC has developed a route-planning aid to assist a planner in identifying the least lethal path through a very dense threat area. This aid does an excellent job of identifying a path and guiding the operator. In particular, the aid makes maximum use of terrain masking in its selection of a route. Unfortunately, the aid takes a relatively long time to calculate the optimum path.

The approach often used for path optimization is called a branch and bound search with dynamic programming. This technique first constructs a state space which for a single altitude flight is a two dimension array with each cell representing a geographical position. Each cell of the array has a value corresponding to the lethality/time for that position. Given a start location and an end location the problem is to find a path through cells whose sum is the lowest. This is done by an algorithm creating a route from the start (or end) cell. The algorithm checks each cost of each move to adjacent cells (plus the sum of moves already taken) and compares it with the cumulative costs of all previous moves rejected. The least cost move is chosen (branch) and that route is extended (bound) and the process repeats. As the lowest cost move is always extended first, the first route to reach the goal is the least lethal. If a cell that had previously been entered by another route is entered again by another route, the second route is dropped from consideration as redundant (dynamic programming). (reference 1)

The branch and bound with dynamic programming technique has the advantage of being a comprehensive search without searching out all possible paths. Its disadvantage is that it normally involves a huge number of alternatives. This occurs because it must have frequent regressions to extend paths. The number of routes examined is thus a function of the size of the state space and the threat distribution. Although some techniques can be used to speed this process, additional capabilities (variable altitude, EW tactics, etc) exponentially increase the size of the state space (making it a n-dimension array) and thus exponentially increase the time to complete the optimization.

2. DECISION AID FOR THREAT PENETRATION ANALYSIS (DATPA)

2.1. DESCRIPTION:

2.1.1. DATPA works to simplify the search process by dramatically reducing the number of feasible routes. The operating heuristic of DATPA is that it is desirable to go around threats or, in the absence of a threat, go straight toward the goal. Distance (fuel) limitations will also set limits on the allowable deviation from a direct course toward the goal. This dramatically reduces the number of possible routes. In its present state of development DATPA makes the assumption that lethality/unit time for a threat is essentially constant across its engagement envelope. Note, this does not mean it is less lethal to be at the center of a threat envelope as at its periphery since the time of exposure would normally be higher at the center. Obviously, this assumption detracts from the

purity of the aid, but it allows for great growth potential.

2.1.2. DATPA uses a technique called "object-oriented" programming where the objects are the threats. These objects have all the characteristics of the threats, including the methods for avoiding the threats, stored with the threats. DATPA does this by creating a series of data structures. The first set of structures defines each of the types of threats in a generic sense. This includes the threat capabilities against various penetrators, threat range at various azimuths, and the susceptability of the threat to EW. These descriptions use the FLAVORS functions of ZetaLisp and include all the basic threat characteristics (methods) for going around the threat without being exposed to it. These data structures are generic since they do not contain any information pertaining to the specific location of the threat. The methods in the structures require additional data such as the number of penetrators, type of penetrators, penetrator speed, EW, etc. These additional parameters are automatically passed to the functions as the aid solves the penetration problem. As each actual instance of the threat is created an instance of the flavor for that type threat is created. As this is done the terrain masked threat edge is calculated using a terrain masking technique similar to that defined by SCT (reference 2). The masking algorithm develops a series of rays from the threat location to the point at which the threat is masked for a given above ground level altitude. This point is defined as the terrain masked edge of the threat. As the terrain masked edge is calculated the azimuth dependent characteristics of the threat are also included. This is done by defining the edge of the threat as the limit of terrain masking or the threat range on a "bald" earth. The threat range is contained in a list for that generic threat type (corrected for orientation). Thus the threat need not be circular or even symmetrical. The calculated terrain masked edge is defined by two lists (one being the reverse of the other) that define the point to point moves around the threat. These lists loop back on themselves and form the clockwise and counterclockwise moves around the threat.

2.1.3. DATPA next constructs a large two-dimensional array with the array indices corresponding to map coordinates. In this sense the DATPA starts like other planners, however it differs from them in what is stored in each cell of the array. Rather than store only the lethality for that map position in each cell, DATPA stores a list of each threat that can illuminate that cell position. The lists of threats are updated as the rays for each threat are extended for terrain masking. This means that once a cell is addressed, all threats of interest are known and through the data structuring all the unique characteristics (threat location, type lethality, etc) are also known. In addition, since the threats types are known, the paths for going around the threats are also known. Finally, this data also allows an estimated lethal exposure to be calculated for each of these paths.

2.1.4. Using premise of moving on threat edges and the data structure described above, the aid can construct a series of routes from a starting location to some goal. Each route is constructed using the DEFSTRUCT function of Lisp and contains the actual route, estimates of lethality and distance, EW capabilities, fuel, etc. As the route is extended fuel, loading, speed, etc can change. The routes are constructed using the following rules:

2.1.4.1. In the absence of any threat, go straight toward the goal.

2.1.4.2. Upon encountering a threat (array cell illuminated by a threat) from a straight line, have the threat project the present route around the threat and have the threat construct a new route (branch) going the other way around the threat. Note the threat constructs the alternate routes as extensions to the existing route (binding). This is done by the threat because the threat data structure contains all the information about the best paths around itself. As these routes are constructed, calculate the lethal exposure and the distance of each. Thus two routes (clockwise and counterclockwise) would be established.

2.1.4.3. Upon encountering a new threat while going around another threat, project the present route through the new threat, construct another route in the same direction (clockwise or counterclockwise) around the new threat, and construct third route in the opposite direction around the new threat and through the present threat. Since the threat characteristics are known the aid can determine the lethal exposure and the distance of each route.

2.1.4.4. Whenever new routes are created, all previous routes are compared with the new routes and the best route (based on lethality and distance) is extended.

2.1.4.5. If multiple threats are encountered simultaneously, new routes are created and the existing route is extended for each threat as described above.

2.1.4.6. Routes that exceed distance/fuel limitations are eliminated.

2.1.4.7. If the same position is reached by two different routes, the second route is eliminated from the list of possible routes (dynamic programming). The logic is that since the least lethal route is always extended first, any subsequent route that reaches the same spot must be non-optimum.

2.1.4.8. Exit going around a threat when the goal can be seen.

2.1.5. The above rules create many partial alternate routes, always extending the most favorable route. Thus, the first route to reach the goal becomes the least lethal. This route has also made maximum use of terrain masking. Additional rules are added to avoid loop backs and redundant routes. This technique is called a branch and bound search technique with dynamic programming and is similar to other route planning aids, but here the number of permissible routes is drastically reduced. Throughout this process the main program does not know how to extend a route. Instead, it gets this information and the lethality data from the individual threats. This simplifies the software and makes it easy to add/remove/modify threats or threat types. As threats are added or moved, only the cells illuminated by the threat need to be changed by adding or subtracting the threat name. The interaction between threats does not need to be changed since that is only calculated as the route is built. Figure 1 shows an example of a route found by DATPA. As can be seen the route proceeds from the point of origin ('s' position) directly toward the goal ('x' position) until a threat is hit. Two alternative routes are then examined around the threat. Since both routes have a zero lethal exposure, the shortest route is selected. Note that DATPA, as written, does not give a final route. The route in figure 1 can be shortened to go directly from the start position to the threat edge. Figure 2 shows a line of threats with a DATPA generated route. Here, DATPA checks routes alternately extended clockwise and counterclockwise outward from the center threat until a point was reached where a route could be found around all threats. If the range precluded going around all threats, those routes exceeding the range would be rejected and the least lethal remaining route would be selected. Figure 3 shows a case where there was a distance limit. The route chosen is not the shortest through the threats, but rather the one with the least threat exposure while still within distance constraints. Once again DATPA ,as written, does not give a final route but merely demonstrates a technique. In addition to the route smoothing, the routes in the examples should also be limited by aircraft characteristics and tactical considerations. These features would need to be added for a deployed system.

2.1.6. The previous description was for finding the least lethal route for a single speed and single altitude with no electronic warfare. However the speed of the aid and its basic architecture allow other characteristics to be examined. For example, if it is possible to negate a single threat of a given type (through jamming, Wild Weasel etc) a question arises as to which route is best and which threat should be negated. For this case, as the DATPA is developing routes and it encounters a threat which is of the type that can be negated it creates an additional route ignoring that threat and eliminating the possibility of negating any other threats. Thus new routes are built and compared that reflect the elimination of various threats. The first route to reach the goal is again the least lethal and, in addition, it shows the best threat to eliminate. Figure 4 shows another route by DATPA where the system was given the capability to destroy one of the small threats but none of the large threats. The threat destroyed and the route chosen are shown. Alternate routes were examined by the aid but they would have involved greater distances. Similar techniques can be used to determine the best speeds to use, best altitudes, or other variable mission parameters. In each case additional routes are created (reflecting the mission parameter of interest) and compared. It would also be possible to use the DATPA architecture for an aid that would have multiple sorties and would determine the best use of defense suppression or saturation techniques. An actual system could eliminate much of the code in the proof of concept version, but would require additional programming to generate final routes and to use real aircraft polynomials.

3. LIMITATIONS:

3.1. DATPA is not the panacea to mission planning. While it offers significant advantages, it will also require human interpretation and other tools. In addition, the DATPA technique does have some limitations.

3.1.1. DATPA does not incorporate all the considerations (ie navigation aids, minimum/maximum leg length, etc) presently used in planning. Some of these could be added without problem while others may be best left to an operator interacting with the software.

3.1.2. DATPA also does not yield the mathematically optimum route since it limits routes to threat edges or direct paths toward target.

3.1.3. Finally DATPA is sensitive to threat positioning and altitude for terrain masking. This limitation, which DATPA shares with other terrain masking tools, makes the route validity very much a function of the threat uncertainty. Additional studies should be conducted to quantify this limitation and to develop workarounds (eg position the threat at the highest altitude within its uncertainty envelope).

4. ADVANTAGES/GROWTH

4.1. The primary advantage of DATPA is its relative high speed. The concept demonstration can find the best routes in extremely complex environments in less than one-half minute simultaneously defining defenses to be suppressed. Although this is a simplified version of a deployed system, it is not optimized for speed. In fact, the existing system has a great deal of code to slow down the process to make it easier to demonstrate. Thus a deployed system incorporating actual weapon system polynomials should have better times. The actual time is a function of the density of the threat and the complexity of the task (speed changes, EW, etc) required. This speed allows the DATPA to incorporate additional characteristics that are not feasible with slower techniques. This is a key point. The slight threat simplifications made by DATPA plus its basic architecture, make a wide range of planning activities possible. In addition to the items mentioned above, it would be possible for DATPA architecture to deal with routes involving standoff weapons, threat degradation through EW, excluded areas, and target prioritization.

5. RECOMMENDATIONS/CONCLUSIONS:

5.1. DATPA as it exists now is strictly a demonstration version written in ZetaLisp and running on a Lisp machine. A deployable version of the concept should be built on a machine presently used by mission planners using actual threat data and weapon system polynomials. In addition, the strategic and tactical planners should be surveyed to identify growth areas for DATPA. These growth capabilities should be incorporated in the deployed systems architecture. Finally, the deployed system should incorporate characteristics such as navigation aids, map preparation, route summary, etc to make it easier for the operator.

5.2. DATPA has met its original goal improving the threat penetration analysis process using heuristics. While not yet creating a human's global perspective, DATPA's data structure gives the system the capability to look ahead and project feasible alternatives while avoiding a large search problem of infeasible alternatives. The techniques used in DATPA are not particularly complex, difficult, or new. It is a symbolic system using simple heuristics, but it is not a 'rule' based expert system. Its benefit is not complex mathematical sophistication, but rather the tremendous advantage of speeding a process even at the slight loss of precision. This principle opens the door to a wide range of future applications.

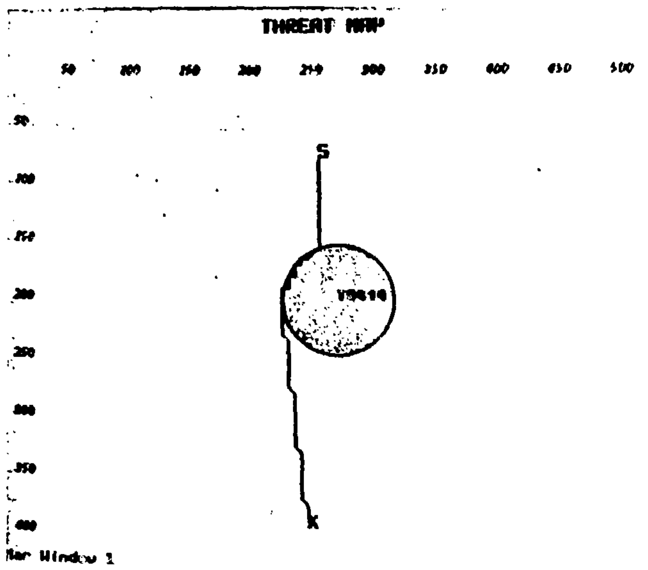

Figure 1
DECISION AID for THREAT PENETRATION ANALYSIS

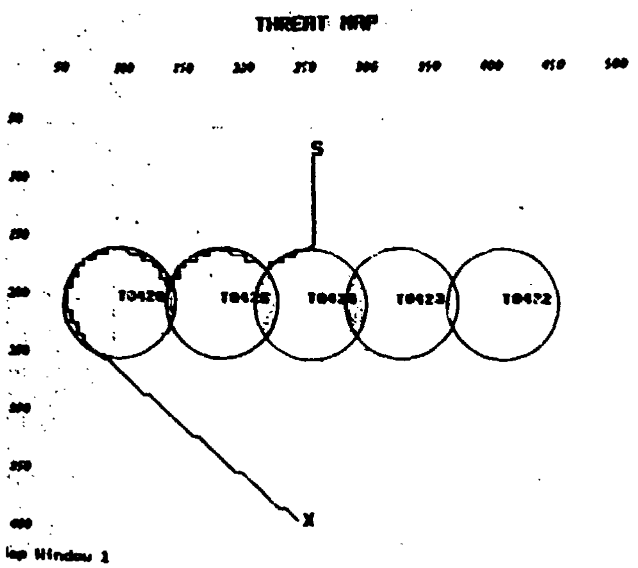

Figure 2
DECISION AID for THREAT PENETRATION ANALYSIS

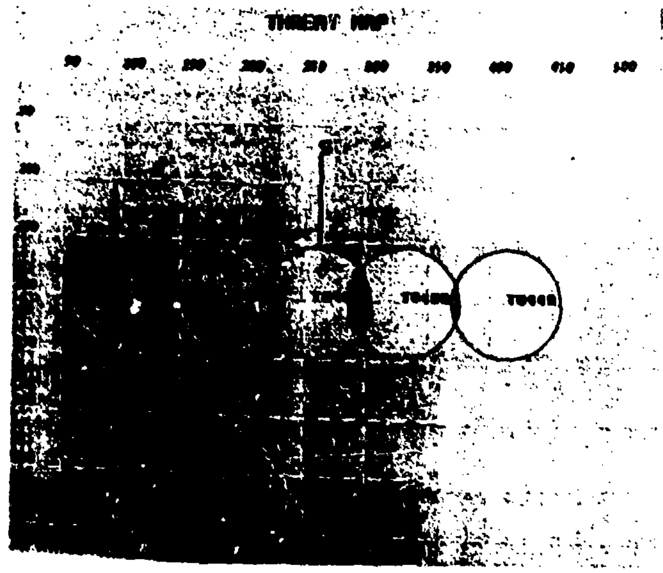

Figure 3
DECISION AID for THREAT PENETRATION ANALYSIS

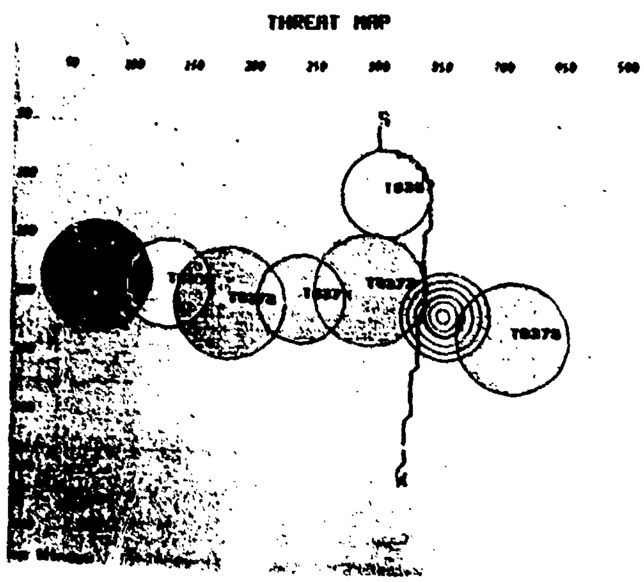

Figure 4
DECISION AID for THREAT PENETRATION ANALYSIS

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DISCUSSION

R.W. MacPherson, Canada

Could you explain again why the path chosen stayed "glued" to the threat circles after it appeared obvious that it could proceed directly to the target?

R.J. Kruchten

The path shown is an artefact of the way the path was calculated by applying the heuristics. As was said in the presentation, further processing is needed on the path shown.

AD-P005 429

ARTIFICIAL INTELLIGENCE AND ITS IMPACT ON COMBAT AIRCRAFT

by

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SUMMARY

As the threat becomes more sophisticated and weapon systems more complex to meet the threat, the need for machines to assist the pilot in the assessment of information becomes paramount. This is particularly true in real-time, high stress situations. Real-time is defined as whatever time is necessary to perform these functions or tasks. The advent of artificial intelligence technology offers the opportunity to make quantum advances in the application of machine technology. However, if AI systems are to find their way into combat aircraft, they must meet certain criteria. They must be responsive, reliable, easy to use, flexible, and understandable. This paper compares these criteria with the current status and concludes that significant additional progress must be made before an AI system can be used in a combat airborne application. Current AI systems deal with non-real time applications and require significant user interaction. On the other hand, aircraft applications require real time, minimum human interaction systems. In order to fill the gap between where technology is now and where it must be for aircraft applications, considerable government research is ongoing in NASA, DARPA, and three services. This paper briefly summarizes the ongoing research. Finally, recognizing that AI technology is in its embryonic stage, and the aircraft needs are very demanding, a number of issues arise. This paper delineates these issues and provides findings where appropriate.

POTENTIAL BENEFITS OF ARTIFICIAL INTELLIGENCE

As the threat becomes more sophisticated and weapon systems more complex to meet the threat, the need for machines to assist the pilot in the assessment of information becomes paramount. This is particularly true in real-time, high stress situations. Real-time is defined as whatever time is necessary to perform these functions or tasks. For example, during the ingress/egress portions of a flight, a machine could alert the pilot to the presence of a threat, suggest/use countermeasures, and/or recommend an alternative flight path. During the target acquisition phase, the machine could recommend target priority, the appropriate weapon and the firing sequence of the weapons. During the entire flight, a machine could monitor the aircraft systems "health", diagnose problem areas, indicate the effect on the mission and reconfigure the system where feasible/appropriate.

Although one normally thinks of a high performance combat aircraft performing these functions, the helicopter must not be neglected. This is most evident when one considers the pilot workload implications which attend a single crewperson operating at night in adverse weather at altitudes which seldom exceed 30 feet. A system of AI augmented capability is required for both flight path and mission management.

In the easier "non-real" time portions of the mission, a machine could plan mission events, generate realignment options and also evaluate options for degraded missions. For training, a series of "machine experts" could act as instructors and as a by-product also provide the documentation of much of the expert's knowledge/expertise which for the most part may not have been disseminated and thus lost.

The advent of artificial intelligence technology with the machine assessing, and in some cases controlling information from many internal and external systems should lead designers to think more of integrated avionics systems. Sensors will provide information that will dictate the flight path. Flight surfaces in a damaged situation will be automatically controlled depending upon damage assessment and countermeasures will automatically be implemented dependent upon the assessment of the threat. Areas which must be considered in addition to artificial intelligence, include the avionics architecture, processors, displays, and the man-machine interaction.

WHAT MAKES AI DIFFERENT

In contrasting AI with what is typically recognized as engineering problems, there are major differences. Engineering applications usually concern well-defined problems for which the path to the solution is known, the algorithms are well-defined (e.g. FFT), the memory requirements are fixed and the execution time is "pre-determined". On the other hand, for AI, the problem is not well-defined (no closed solution exists), and the solution path is determined "on the fly" and changes as the world changes. In doing this, the AI system examines the current state of the world and reacts to it according to a pre-defined set of rules. The system must also be able to support some means of back-tracking to determine if the conditions are still the same.

REQUIRED CHARACTERISTICS OF AI SYSTEMS

In order to AI systems to find their way into combat aircraft, they must meet certain criteria. The following is a brief summary of some of the more important areas.

Responsive - An AI system must provide needed information when it is required. This is particularly true in "real time" situations where decisions must be made in a matter of seconds.

Reliable - The question of how reliable the system must be depends on what functions it is intended to perform and whether it is in a control or advisory role. Since AI is intended to perform heuristic reasoning to deal with complex situations with incomplete or uncertain information, one can only expect it to produce a solution that is pretty good most of the time i.e., only as good as the experts. Realizing that an AI system will never be 100% reliable does not avoid the issue of identifying how reliable it actually is. This gives rise to the question of testing and evaluation of intelligent systems. Currently, there are few metrics for the evaluation of these types of systems. In summary, the question of reliability is an area that needs considerable work.

Easy to Use - An AI system, if it is to be useful, must be easy to use. That means the pilot should be able to interact with the machine in a simple manner. Means of interaction include speech, displays, and tactile IO (touch panels, etc.). The cockpit environment for this interaction must be considered i.e. noisy, stressful along with the different speaker types and styles and graphic presentation of complicated information.

Flexible - An AI system should be able to adapt to the situation, both internal and external. The system, for an ideal case, should be able to evaluate the pilot's condition and present information which is appropriate for that situation. Also since the AI system will be conveying a different type and potentially greater quantity of information to the pilot, although possibly in a more concise or condensed form, new requirements in interface media may be needed.

Understandable - An AI system has the ability to explain its reasoning. This explanation of the reasoning and decision making is one unique requirement for a pilot communicating with the AI system. Also since the pilot may have knowledge in priorities unknown to the system, he should be able to redirect, reject, or seek another solution.

AI Technology Status/Needs - Table I presents major categories of an AI system, the current status and what is required for airborne applications. As can be observed from this chart, significant additional progress must be made before an AI system can be used in a combat airborne application. Current AI systems deal with non-real time applications and require significant user interaction. The rule base is usually less than a thousand and has limited man-machine interaction (e.g. voice recognition - 100 words in a non-stress environment). The hardware's architecture allows only sequential operations highly constraining real time applications. And finally, researchers are only beginning to scratch the surface in understanding how to extract knowledge from the expert and representing that knowledge for machine operations. On the other hand, aircraft applications require real time, minimum human interaction systems. The rule base will greatly exceed 1000, and voice recognition of 1000 words under high stress conditions will be required. Machines having architectures allowing parallel operations for real-time applications along with an easily developed/modified knowledge base will be needed.

STATE OF THE TECHNOLOGY FOR INTELLIGENT AIDING IN THE COCKPIT

TECHNICAL AREA	CURRENT CAPABILITIES	DESIRED/REQUIRED CAPABILITIES
expert systems	Non-real time	Real Time
	Reasoning about static situation	Reasoning about dynamically changing environment and time-based information
	Limited capability for dealing with uncertain, incomplete, or inconsistent information	Rigorous methods for dealing with uncertainty
	Rule-based systems (1,000 rules)	Model-based systems 1000-10,000 rules
	Limited control structures	Efficient control structures for dealing with multiple representations
	Limited explanation capability	Extensive explanation capability as needed
	Symbolic computation	Hybrid reasoning about symbolic and numeric information
	Single expert	Multiple cooperating intelligent systems
knowledge representation	Limited expressibility	Representations for temporal, spatial, qualitative, default, functional, structural and analogical knowledge
problem solving/planning	Well-defined, fixed goals, conditions, objects and properties	Dynamically changing goals conditions, objects and properties
	Single Agent	Multiple Agent
	Non-overlapping events	Simultaneous and overlapping events Temporal relations Plan execution monitors Incremental Planners
Speech Understanding	100 words, restricted language	1000 word vocabulary, connected speech, natural language
Computer Hardware Crew	Sequential operations	Parallel operations
Crew Interface	Non-flexible and limited capability	Crew information requirements by (intelligent systems) function Adaptive aiding Multiple interface media Natural human-like Communication

TABLE I

Ongoing Effort - In order to fill the gap between where the technology is now and where it must be for aircraft applications, considerable research is ongoing. The following is a brief summary of the pertinent efforts.

DARPA - DARPA has initiated its Pilot's Associate Program as part of its strategic computer program. The Pilot's Associate Program will have as its focus a demonstration that will both challenge the technology base programs, and that will show the military potential and the utility of transitioning this work to service programs. Such goals as cooperating expert systems, processing speed through parallel processing, and new ways of information portrayal for pilots provide major program direction.

NASA - The following are the applicable ongoing NASA programs:

- Inflight Fault Monitoring and Diagnosis - This work is concerned with onboard fault detection and diagnosis as an aide to the flight crew. The purpose of the work is not only to identify the failure within the aircraft but also to identify its effect on the aircraft capabilities and functions.
- Crew Error Tolerance - This work is concerned with detecting crew errors and identifying them to the pilot.
- Crew Interface with Intelligent Onboard Systems - This work is concerned with humans interfacing with intelligent onboard systems. This includes using AI for intelligent interfaces (e.g. natural lagnuage understanding for voice I/O), the content of the interface between the pilot and specific intelligent aids, and the interface media used for the communication.
- Navigation and Guidance
- Planning Tools - This work is mainly focused on space applications, but many of the basic concepts apply to aviation as well.

ARMY - The Army has established as Centers of Excellence for AI, the Universities of Pennsylvania and Texas. The following is a brief description of these efforts:

University of Pennsylvania - interaction with dynamic data base, flexible data type systems, movement representation, 3-C vision and robotics.

University of Texas - problem solving, text knowledge systems, problem solving with uncertainty, search techniques, parallel architecture.

The Army also has the following efforts underway:

- Helicopter Mission Planning and Enroute Navigation - Stanford Research Institute
- AI Theory and Reconfigurable Control Systems - Princeton University
- Study in Natural Multi-Media Communications - Louisiana State University
- Representation and Decision Mechanisms in AI - Duke University
- Role of Experience in Common Sense and Expert Problem Solving - Georgia Tech Univ.
- AI, consultant program/diagnostic troubleshooting
- Army Aircrew Aircraft Integration - AVSCOM
- AI Applications to Army Aviation Systems
- Multiple Expert Resolution - SWL
- General AI - NVEDL
- Decision Aid Supplied to Short Range Air - HEL
- Artificial Vision
- Application of AI to automatic EO Target Tracking and Classification - CSTAL

AIR FORCE - The following is a delineation of the Air Force Programs:

- Investigation of Combat Aids for Pilots by Expert Systems - Systran Corp.
- Adaptive Tactical Navigation - Analytic/McDonnell Aircraft
- AI Applications for Pilot Decision Aiding - Gen Dyn/TI/GE
- Avionics Expert System Definition - BBN, GD, Boeing/AI/DS
- Panoramic Cockpit and Control Display System - TBD
- Threat Recognition and Processing Techniques - TBD
- Unified Trajectory Control System - Lear Siegler
- Cockpit Automation Technology - McDonnell Aircraft, BBN, BDM
- Pave Pillar - TBD

NAVY - The following are the relevant Navy Programs:

- Modeling - ONR - Cognitive Structures and Processes, Human Decision Requirements Man-Machine Interface
- Threat Classification - NRL, NADC, NUSC - ISAR, Acoustics
- Multi-Sensor Information Integration - NRL, NADC - Radar, ESM, Acoustics, Intelligence
- Mission Planning - NOSC, NADC - Air Strike Planning, Tanker Air Refueling Scheduler
- Attack Planning - NADC - ASW Localization/Weapon Launch
- Fault Monitoring/Diagnosis - NRL - Automatic Test Programs
- Target Assessment, Adaptive Control - NWC

PROBLEM EXAMPLE

A typical Navy platform that could be aided by AI is the E2-C aircraft. Its mission is to provide fleet protection by serving as a command and control post. The operators on this aircraft are faced with large amounts of data coming from both the on-board sensors and the data links. After processing, this data is displayed. Because of the amount, rate and diversity of the data, often the displayed information is cluttered and fragmented. This leads to an overloaded operation and hence poor tactical decisions. The ultimate penalty could be fleet destruction.

An AI based solution for this problem could be the addition of an intelligent adjunct (machine) that could be inserted after the information is processed and correlated. The responsibilities of this machine would be to resolve uncertainties and conflicts, provide sound threat assessment and interpret and predict the actions of the threat. The results of having such an adjunct would be a unified, informative display presenting a clear tactical picture leading to an informed and in control operation.

A key component of an intelligent adjunct is the plan recognition model. Plan recognition is a process by which humans interpret/predict the actions of others. Theoretical models have evolved in behavorial science which are symbolic, heuristic in nature. However current plan recognition models/AI techniques cannot deal with threat activity. If one compares the present status of plan recognition against what is required for the tactical problem, significant shortfalls can be identified as follows:

PRESENT PLAN RECOGNITION "Where We Are"	TACTICAL PROBLEM "Where We Are"
o Single Action/Simple Task	o Multiple Actions/Complex Tasks
o Well Defined Goal	o Uncertain Goals
o Constrained Actions	o Unconstrained Actions
o Certainty in Actions	o Uncertainty in Actions
o Limited Revisions	o Multiple Revisions
o Time is not a Factor	o Time is a Factor

This problem is currently being investigated at the Naval Air Development Center, Warminster, Pennsylvania. In order to make the transition from where we are today to fleet operations, significant developments must be made in knowledge acquisition, parallel processing, man-machine interaction, and AI tools (e.g., higher order language).

ISSUES - Recognizing that AI technology is in its embryonic state and the aircraft needs are very demanding, a number of issues arise. These issues must be addressed by both the research and operational communities if AI is ever to realize the expectations people have for it. The following is a delineation of some of the issues.

- o How reliable must an AI system be? (Real Time vs Non-Real Time) How do we determine that reliability?
- o How will we test and evaluate these AI Systems?
- o What should be automated using AI? How far can AI go?
- o What are the limitations on implementing AI in the cockpit? AI Technology, Hardware, Pilot-Machine Interface, Pilot Acceptance.
- o How adaptable will the AI System be?
- o How are multiple AI and non-AI systems coordinated? How are conflicts between them resolved?
- o How should the emerging AI technology be integrated with conventional automation?
- o What special requirements exist for communicating between pilot and AI system?
- o How far can AI go in being a successful training device?
- o Can a real time AI system be made cost effective?
- o Is the current ongoing research work in AI addressing the key issues, if not what should be done?
- o What are realistic expectations for AI for aircraft entering service in 1990, 1995, 2000 and beyond?

Findings - After reviewing the operational need, the current state-of-the art, the on-going research efforts and the questions still unanswered, one can conclude the following:

- The areas in which AI could be the most benefit will be the most difficult to implement. The Combat Aircraft Pilot is faced with making life-deciding decisions in an uncertain, high stress environment. These decisions in many cases must be made in a matter of seconds. However, for AI to be able to aid in these situations, significant progress must be made in all aspects of the technology.

- Development is needed in - knowledge acquisition, parallel processing, man-machine interaction and AI tools (e.g. high order language).

- Ongoing research efforts could be better coordinated - As noted earlier in this paper, considerable research efforts are ongoing in DOD and NASA. If information from these efforts was shared among the workers, duplication could be avoided, the most pressing issues addressed, and applications to combat aircraft be available earlier.

- Expectations for AI should be in consonance with reality - Currently many people feel AI will be a cure-all. However, as mentioned earlier, since AI is dealing with heuristic information it is unrealistic to think it will be 100% reliable. (Nothing we have now is 100% reliable.) Again one has to identify the roles of AI in providing advice or actually controlling events. Once that role has been defined, realistic goals can be formulated and research performed on the outstanding problems.

- Designers should be thinking of system integration aspects of AI - Since aircraft have a minimum life of 30 years, it faces a changing, ever more sophisticated threat. Designers of avionics systems should keep this in mind and attempt to extend their vision to ensure new technologies, such as AI, can easily be integrated into the avionics system. For example, it is envisioned the AI systems of varying degrees will be available over the next 25 years. Combat aircraft for fleet introduction in the 1990's are currently being formulated. These aircraft should be so designed to easily accept the AI advances. This is the responsibility of the systems architect.

Advanced Sensor Exploitation

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SUMMARY

This paper describes the Advanced Sensor Exploitation Testbed developed by the Rome Air Development Center for the purpose of evaluating and testing advanced techniques in the area of multi-sensor, multi-discipline correlation. The Testbed consists of three subsystems: 1) the scenario generation subsystem, 2) the sensor simulation subsystem, and 3) the correlation and exploitation algorithms. The scenario generation subsystem, referred to as Dynamic Ground Target Simulator, is a computer automated system for the development of "ground truth". Ground truth is any activity that occurs in the battlefield in relation to movement or emission of opposing ground forces. The sensor simulation subsystem consists of generic moving target indicator, radio detection/location, radar detection/location and imaging type sensors that act as filters for the ground truth. Ground truth data is filtered out (undetected) depending on local terrain and sensor operating characteristics. The correlation and exploitation algorithms are resident within the Advanced Sensor Exploitation Element and provide such data as military unit identification, the identification and tracking of high priority/critical targets, threat alerts and activity level indications. The Advanced Sensor Exploitation Testbed along with built-in evaluation routines allow for the development, test and evaluation of automated correlation and identification algorithms in as a realistic environment as possible.

ASE TESTBED

The ability to strike mobile second echelon ground forces before they can take advantage of any breakthroughs created by the first echelon is a paramount objective of the Air Force in a limited tactical environment. Limited air resources must be applied most effectively against the large number of possible targets. Due to the dynamics of the tactical battlefield the assessment, decision and deployment of those resources must be accomplished in a timely fashion. The requirement by the tactical decision makers to have accurate, up-to-date, and continuous data on the position and status of the opposing ground forces has precipitated the development of high-volume advanced sensor systems. These sensor systems have been designed to exploit a specific target characteristic such as movement or emissions and provide a high volume of information in near-real-time.

The sensor data, once correlated and fused, will be integral to a data base that can be exploited by target and threat identification and tracking algorithms in order to provide the necessary information required by tactical decision makers. The dynamic value of the sensor data, the timely requirement for information and the volume of data to be processed predicates that automatic correlation and exploitation functions be utilized.

The Advanced Sensor Exploitation (ASE) Testbed was developed by the Rome Air Development Center (RADC) to test and evaluate the advanced capabilities in automatic correlation, processing and display of the products of the advanced sensor systems such as the Moving Target Indicator, Imaging, Radio and Radar Detection type sensors. Functions which have been developed and demonstrated include: the ability to correlate data from multiple sources and multiple sensor disciplines, the ability to continuously track high priority targets, the ability to specifically identify critical nodes, the ability to automatically issue threat alerts when friendly air missions are potentially threatened by enemy Air Defense Units, and the ability to cue sensors to change modes or to observe specific areas or signals of interest. Also developed was an evaluation module to determine the accuracy and effectiveness of the ASE algorithms and a test environment that consists of a scenario generation system called the Dynamic Ground Target Simulator (DGTS) and the appropriate sensor models.

SCENARIO GENERATION

Due to the complexity and time requirements involved in the preparation of scenario data it was decided early in the ASE program to develop a modular, flexible scenario generation tool that would provide simulated ground target movement, communication and air defense activity of an opposing force. This automated scenario generator, referred to as Dynamic Ground Target Simulator, (DGTS), permits a variety of scenarios for testing purposes with minimum preparation time.

DGTS is composed of two main elements. A model construction subsystem, which provides automated tools and a methodology for the model building process, and a scenario generation subsystem which schedules and executes the events included within the models and allows interaction with the scenario to add additional events or change existing events.

The most important features of the model construction subsystem are the model definition language, which is based on PASCAL, and the model librarian. This definition language forces a structured approach to the model building process. It also encourages modular development of models which is an important consideration whenever new models must be constructed. Appropriate modules from previously developed models may be utilized and the system capabilities continue to grow with the development of each new module. The model construction subsystem also contains a librarian function which allows modules to be inserted, removed or replaced, while ensuring the necessary links to other modules within a given model are maintained. In addition to developing the model definition language, it was necessary to develop a translator for the language. This capability was provided by modifying a PASCAL compiler.

The scenario generation subsystem contains two components: a scenario executive which performs the bookkeeping function for the system, and a scenario monitor which allows a man-machine interface. The scenario executive schedules and executes events starting with initial orders received from a text editor. This process begins after the model has been constructed. The executive interacts with the model file to produce a scenario file based on the events listed in the model file. It also interacts with the scenario monitor. The scenario monitor permits interaction with the scenario through a graphic display. Events can be added or modified through the scenario monitor. Three options are provided to allow events to be added at any point in the scenario: events may be added and scheduled to begin immediately or they may be scheduled to begin in some specified length of time or they may be scheduled to begin at some specific time in the scenario.

Scenarios have been developed from the Motorized Rifle Regiment to the Combined Arms Army level operating within a 200km x 200km area based around the Fulda Gap region of Germany. Activities reflect the hierarchical nature of the military unit as well as military doctrine. Deterministic unit movement, vehicle movement, communications activity and air defense activity are contained within the models. In addition, there is probabilistic communication and air defense activity incorporated. Physical realities such as cartographic features, terrain, weather and their effects have been included.

The Dynamic Ground Target Simulator has been implemented on Digital Equipment Corporation's VAX 11/785 utilizing a RAMTEK display system for all user interactions and graphic displays. The DGTS system provides an event driven, deterministic simulation approach. A variety of scenarios can be generated utilizing the system simply by varying initial order conditions, entity data or via on-line interactive event scheduling. Scenarios are recorded for future playback and all generated scenario data can be viewed on the RAMTEK graphic display system.

SENSOR SIMULATION

Sensor simulation became a requirement for the ASE Testbed due to the unavailability of sensor output data. Also, a need arose to be able to generate sensor data utilizing varying operating characteristics in order to fully test the exploitation functions.

The sensor simulation portion of the ASE test environment consists of three subcomponents: 1) the sensors, 2) the platforms, to the extent that sensor performance is altered by a characteristic such as altitude or flight path, and 3) the information content of the output of a sensor ground processing station. The test environment currently includes generic models of an MTI sensor, a radio detection/location sensor, a radar detection/location sensor and an imaging sensor.

Ground truth information which has been generated utilizing the DGTS system is sent to the sensor systems. Based on the sensor and sensor platform characteristics as well as environmental factors such as terrain and weather at the time, a determination is made as to whether or not a detection has been made by the sensor. If it is determined that a detection has been made, messages are sent from the ground processing station to the correlation and fusion functions regarding the detections. Errors are introduced into the system at each step of the information flow process to maintain as much realism as possible.

The sensor simulation package has been implemented on a VAX 11/785 utilizing FORTRAN as the programming language. It should be noted that the sensors are simulated only to the degree required to provide realistic data to the correlation and fusion algorithms and do not consist of any full scale simulations or complex calculations.

EVALUATION

The evaluation subsystem of the ASE Testbed consists of two phases: on-line evaluation and post-experiment evaluation. On-line Evaluation is a set of software and procedures which is modifiable either at time of experiment initialization or during the course of an experiment. The statistics gathered as a result of this data gathering process can be displayed continuously or as required. This permits judgements to be made as to whether the experiment is proceeding properly and whether the proper data is being gathered. If not, modifications can be made as the experiment progresses.

The Post-Experiment Evaluation process includes the software necessary to collect the data which was archived during the On-Line Evaluation phase and to massage the data so that post-experiment analysis can be done. Post-Experiment evaluation also utilizes the ground truth file created by DGTS and other files which were accessed during the experiment. Products created by the Post-Experiment Evaluation process include a trace of all functions utilized, a trace report of any products produced by any of the algorithms, a list of any "ground truth events" not detected by the sensors, and a data base activity report.

ASE ELEMENT

The ASE Element is the segment of the ASE Testbed where all of the multi-sensor exploitation functions are implemented. The ASE Element software performs rapid correlation of information obtained from both the advanced, near-real-time, high volume sensor systems and intelligence information sources and utilizes the resulting correlated data base to locate areas of high ground activity, identify military units, maintain a continuous observation of high priority targets, and identify threats to friendly air missions. These tasks are performed by the invocation of six functions; correlation, wide area surveillance, military unit analysis, special target analysis, dynamic situation assessment and automatic threat analysis. Support files such as cartographic and terrain data files, radar and radio characteristic files and unit templating files are utilized by the six functions.

CORRELATION

The ability to fuse the multi-sensor data and display it in a comprehensible format to the user fundamentally depends on the correlation or "association" of the sensor reports to each other. Correlation accepts the sensor reports from all of the sensor types and a C^3I source and integrates these reports into a single data base that is utilized by the other functions to develop a dynamic representation of the battlefield. The data in the correlated data base is stored as either an entity or group. An entity is a radio or radar and a group is made up of several vehicles and may have one or more entities associated with it. New reports are associated with existing data by utilizing radio and radar detection reports for entity to entity and entity to group associations and the MTI, Imaging, and C^3I reports for group to group associations.

When either a radio or radar detection report is received, the confidence level of the sensor target ID is checked. If a high confidence level is indicated, the association file is searched to find an entity previously linked to that sensor target ID. If an entity is found, the association file is updated. Otherwise, a new entity is added to the association file. If the confidence level of the sensor target ID is low, then a measurement of association (MOA) is calculated. The MOA is a formula that weights various attributes such as frequency, position, and pulse repetition interval by their reliability. The MOA is calculated by first filtering out entities that are of a different type or are operating at a different frequency. The remaining entities are given a "closeness measure" which is based on physical location. The "closeness measure" value of each entity is then compared to a specific distance and if the ratio of the former to the latter is greater than one, then the entity and target report are assumed to be the same.

If the target report is associated to more than one entity, a check will be made to see if the entities should be merged. A check is made into each of the candidate entities history files and then an evaluation is made as to whether to combine the entities or not. If the entities are combined, a new ID is given to the merged entities and the old entities are deleted from the data base.

For MTI associations, candidates are first screened by area of interest (AOI). The area of interest is the maximum radius possible given the maximum speed of the group and the time lapsed since the last group report. The remaining candidates are then assigned a MOA which is based on physical location. If the time lapse from the last group report to the current target report is large, then the MOA is calculated based on trafficability. The candidate groups that are remaining are then sorted according to whether they have a strong or weak association to the target report.

For C^3I identification and Imaging sensor reports, the group summary file is searched for groups whose records are closest to the time of the target report. These groups are then screened based on area of interest. Those groups which pass the AOI test are assigned an MOA which is based on physical location. Using predetermined thresholds, the group is given a strong or weak association to the target report based on its MOA value. If a target is associated highly with more than one group, then the history file of each group is checked to see if the groups should be merged. If the groups are merged then the newly formed group is given a new ID and the old groups are deleted.

For entity to group associations, the radio and radar detection reports are checked to see if they correspond with an entity that was previously associated with a group. If a link does exist between the entity and a group then the groups in the data base are screened according to physical location. The MOA is calculated for all groups that pass the screening test. The calculation of the MOA is based on the probability of the entity being associated with the group given the location of the entity. Based on the value of the MOA the entity to group association is given a confidence level. A check is then made into the histories of the entity and group to see if they should be associated together. Those that pass the history check and have a high confidence level are associated together.

WIDE AREA SURVEILLANCE

Knowledge of the level and type of activity across the battlefield is an essential asset when deciding where limited personnel and resources should be concentrated for intelligence collection. Such information would eliminate waste and speed up the identification process of units in regions of high activity. Wide Area Surveillance (WAS) utilizes the sensor reports to build a surveillance map divided into 5Km x 5Km grid cells over the whole cartographic area. Each grid cell indicates the level of activity overall and the level of activity for each sensor type by using a color coded scheme with each color representing a different threshold set by the user.

In determining the activity level of each sensor in the grid cells, the Wide Area Surveillance function counts the number of target reports for each sensor type per grid cell within two separate time periods. The time periods are divided into a short one of five minutes and a long one of an hour except for MTI target reports where surveillance data is already in a surveillance map format so the short interval is already completed. When an end to either time interval occurs, the finished surveillance map is stored and the new data is displayed.

MILITARY UNIT ANALYSIS

The limitation of resources imposed upon a tactical battlefield decision maker makes essential the identification and prioritization of potential targets. Providing the identification capability within the ASE Element is the Military Unit Analysis (MUA) function. The military units can be identified from the correlated sensor and intelligence data by aggregating the groups and entities into larger units and then templating the larger untis' characteristics with characteristics of known units. The Military Unit Analysis function takes the groups and entities and aggregates them into battalions and the battalions into regiments and then identifies these units by their characteristics. The battalion was chosen as the basic military unit because, in non-nuclear conditions, the companies

in a battalion and the vehicles in a company are both spaced 25 to 50 meters apart. This makes it difficult to distinguish from separate companies in a battalion.

MIA aggregates all of the entities and groups from the correlated data base into higher level units. This aggregation algorithm builds higher level units by testing candidate groups to see if they fall within the expected length of the unit currently being built. Once all of the higher level units have been formed, a characteristics vector, which is the combined characteristics of all the elements in the unit is created. This characteristic vector is compared against known units and an attempt is made to identify the unit type and associate with it a confidence level. After the type of the unit has been distinguished, the element IDs of the candidate unit are compared with the element IDs of units already in the data base and if over one-half of the IDs match, then the data base is updated, otherwise a new unit is established in the data base.

SPECIAL TARGET ANALYSIS

An asset to any fighting unit is the ability to disrupt the enemy's command and control. To do this, information about the networks between units is required. Such information is supplied to the user by utilizing entity reports of the correlated data base. From these reports the Special Target Analysis (STA) function can form simplex nets, duplex nets and also identify the nodes and simplex nets by type.

In processing the reports, the Special Target Analysis function creates an entity block if the report incoming is the first one for that emitter. The description of the emitter is updated if the report is the second or greater. The emitter report is then processed further.

If the emitter is a radar, it is first templated to already existing nodes on the basis of co-location. Each node type must contain the radar type, and the node must not have its full complement or the emitter will not be associated to the node. If the emitter cannot be added to an existing node, then a new node is created utilizing unclustered radars and applying the templating process to them. An attempt is made to form additional air defense unit command elements where initial identification was ambiguous. This is done by templating and using additional doctrinal and deployment constraints. If the emitter cannot be associated with a node, then it is put in the unclustered emitter file.

If the emitter is a radio then it can be of two types; simplex or duplex. A simplex radio operates on a single frequency while a duplex radio operates on multiple frequencies. If the candidate emitter is a simplex radio, the function tries to find a simplex net operating at the same frequency and modulation as the emitter. The emitter is then added to a node on the basis of co-location and the fact that no other simplex radio at the node can have the same frequency. If the emitter cannot be added to a node or net then a new node or net is created utilizing unclustered entities. Whenever a simplex net has three or more members it is templated to find its type. Duplex radios are attempted to be added to existing duplex nets or nodes in the same manner as the simplex radios and the unclustered duplex radios are processed to form new nets or nodes. The nodes that are generated are templated to establish their type and any emitter that cannot be associated with a node is put in the unclustered emitter file.

Supernodes are formed from the fusion of radar, simplex radio, and duplex radio portions of a node. Once supernodes have been created or updated by the incoming emitter report they are templated to find their type and identification.

AUTO THREAT ANALYSIS

The Auto Threat Analysis function determines if any air defense unit (ADU) poses a threat to any planned friendly missions. If a threat does occur, a report is issued to the user indicating the threatened mission, the threatening ADU(s) and the legs of the mission that are threatened.

At the start up of the ASE Element and for each mission that is subsequently added, a check is made against every ADU and its coverage envelope. The coverage envelop or threat circle is assumed to be a cylinder centered at the ADU's location with the radius equal to the maximum range of the ADU's missile and the height equal to the maximum effective altitude of the missile. Both the radius and height of the threat circle are determined without regard to the terrain. Also, after a delta time of t, where t is determined beforehand, the STA File is searched for all known ADUs. If there is a new ADU, its characteristics (speed, location, type, and id) are added to the ADU Table of the Auto Threat Analysis function. The new ADU is then checked against all missions in the Threat Table to determine if a threat exists. All the ADUs that were previously recorded in the STA File are compared to their coordinates in the ADU Table and if there is any significant movement of the ADU, it is checked against all the missions in the Threat Table to determine if a threat exists and the ADU's new location is recorded into the ADU Table. Any threats as determined by the Auto Threat Analysis function are sent to the C^3I subsystem indicating mission, threatened legs, and threatening ADUs. This data is then displayed on a Cathode Ray Tube (CRT) screen.

DYNAMIC SITUATION ASSESSMENT

The user may select certain units as being of high priority and wish to follow the development of those units. But data is available on these targets only as long as the sensors can "see" them. Once the sensors lose a target due to shadowing or terrain masking, the user must expend valuable time recalculating all of the possible unit positions for that target. The Dynamic Situation Assessment (DSA) function of the ASE Element eliminates the problem of manual searching for a target once it is lost to shadowing and even identifies those targets that are a high priority.

The Dynamic Situation Assessment function first searches the Dynamic Order of Battle (DYOB) and STA Data Bases to identify targets that are to be considered high priority. When a high priority

target is found its type, ID, and location are saved for later use by the function. For every high priority target at an intersection, the position of the target at the next intersection is projected. The projected path is then checked to see if there will be any sensor loss due to shadowing. If some loss is found, the location of the loss and the sensor type are sent to the task sensor function. This loss information is then used to task the sensor to "look" at the projected exit points of the shadowed area at a time when the target is expected to be there. In this manner, the sensors keep a continuous watch on the high priority targets as identified by the user and the location of the targets is always known.

CONCLUSION

All of the functions of the ASE Element interact with monitor control functions which allow all data generated to be displayed graphically. This data is represented by varying symbols and colors and is overlayed on a digitized cartographic data base. The resulting "pictures" give the user an up-to-date graphical representation of the battlefield. The graphic displays, through the use of a man-machine interface function, allow the user to bring up specific statistics on the exact coordinates, speed, frequency, and etc. of any target in the data bases. This knowledge helps the user in deciding the planning, allocation and deployment of resources within his area of interest.

The ASE Element has been implemented on a VAX 11/785 utilizing FORTRAN as the programming language. All graphics are displayed on the RAMTEK graphics display monitor. Command inputs are made through the RAMTEK display system also. All textual data is displayed on Digital Equipment Corporation's VT-100 series terminals.

Utilizing the ASE Element within the ASE Testbed allows a more realistic evaluation of the functions utilized in the identification of battlefield targets. The modular approach in the design also allows the substitution of Testbed elements or ASE Element functions to test a variety of sources and functions. Planned upgrades and additions to the Testbed will expand the capabilities of the Testbed and provide an even more realistic test environment. Realistic test environments expedite the development of concepts and techniques that provide the user with the information that is required in the most efficient manner possible.

REFERENCES

Allen, Steven D., et al., PAR Technology Corp., Advanced Sensor Exploitation (ASE) Implementation Final Technical Report, May 1983, RADC-TR-82-334, Vol. I.

DISCUSSION

M.L. Busbridge, UK
What database are you using for your line of sight terrain obscuration?

J. Antonik
The database used is the US Defense Mapping Agency's Digital Terrain Elevation Database (DTED). The level of the data is DTED Level III.

R. Cowderoy, UK
How much of the system has been constructed and how is the system being demonstrated?

J. Antonik
All of the functions and capabilities discussed in this paper have been constructed and implemented. The system is being demonstrated at RADC on a VAX 11/785 utilizing a RAMTEK graphics system. Graphic symbols (military units and such) are overlayed on a digitized cartographic database of the area of interest.

AD-P005 431

INTEGRATED MULTISENSOR TARGETING

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SUMMARY

The integrated multisensor targeting effort presented in this paper is a United States Navy Exploratory Development program directed at the development and demonstration of multisensor targeting algorithms for air-to-air application. The program for developing the capability is described. The current algorithm development is presented. The simulation tool and the real-time system which support the development and demonstration of the algorithms, respectively, also are described, and finally the plans for testing the capability are discussed briefly.

INTRODUCTION

Future air combat and attack environments will confront the pilot with a density and diversity of targets, defenses, and countermeasures that may overload the unaided single- or two-place aircrew. This paper describes a computer-based multisensor targeting (MST) system development, which will combine multisensor data in real time to generate an integrated MST display for air-to-air combat. This is a critical function which is needed to support the future development of an automated knowledge-based information processing system that integrates and controls various aircraft sensors for fully automatic target detection, acquisition, identification, and tracking.

The ongoing program is a Navy exploratory development program directed at the development and demonstration of an MST tracking algorithm. Targeting outputs from a multifunction radar, an infrared search and track (IRST) set, and a passive intercept receiver are being integrated and correlated to provide accurate, high-confidence multisensor targeting in the highly dynamic air-to-air combat environment under all conditions of weather, visibility, and electronic order of battle.

A real-time demonstration system is being developed to demonstrate the algorithm. The system is being designed for flexibility of use. It will be capable of simultaneously accepting sensor data, processing the MST data, archiving time-correlated sensor data (both raw and processed) and MST data for later analysis, and generating MST symbology for presentation on a graphics display. A rugged host computer is used to implement the system for use in the laboratory or at a ground-based test site. A non-real-time simulation system also has been assembled to support the development, test, and evaluation of the algorithms in the laboratory under simulated test and air combat conditions. The non-real-time simulation also provides a capability to simulate sensor outputs for driving the real-time system in the laboratory as part of the system integration and checkout prior to field integration of the system with real sensors.

SIMULATION

Because of the limited resources available to support an exploratory development project, the design philosophy of this program has been to make maximum use of existing software and facilities. The creation of a multisensor air-to-air simulation is an example of the application of this principle. An existing radar-only simulation was modified to add the additional sensors needed. The basic simulation, called SLAATS (System Level Air-to-Air Tactical Simulation), was developed by the Weapons Department of the Naval Weapons Center. It is written in Simscript, a higher-order computer language with special features designed to facilitate simulation writing, and includes an event timer and linked-list storage structures.

SLAATS is a dynamic air combat simulation which models each aircraft as a network of intercommunicating subsystems (see Figure 1) that interact by exchanging discrete messages. This structure made it possible to add additional sensors to the aircraft in a straightforward way. SLAATS operates in finite time steps, with typical event-to-event separations on the order of 1 second. For multisensor tracking, the most important events are the end-of-frame times of each sensor when the sensor's updated track files are transmitted to the multisensor tracker. Aircraft dynamics are normally updated at a one-per-second rate and are modeled with three degrees of freedom so that aircraft orientation is specified by velocity and acceleration vectors.

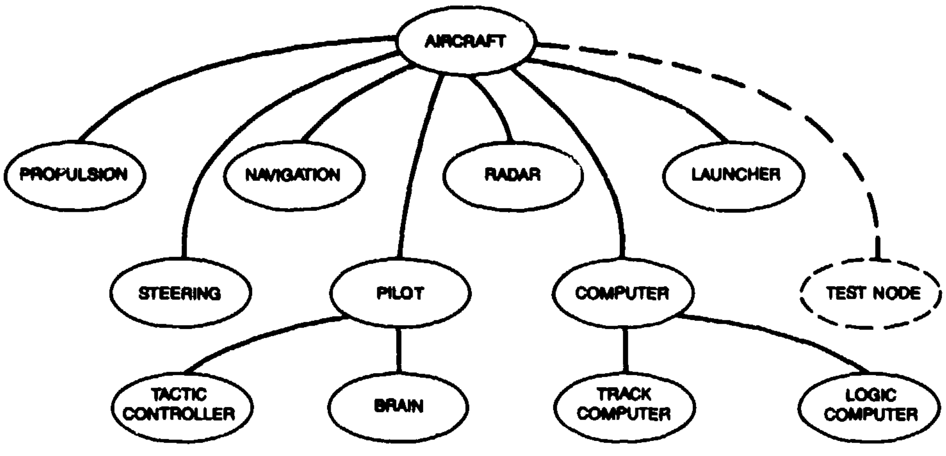

FIGURE 1. SLAATS Node Tree of an Aircraft.

To make SLAATS a multisensor simulation, a new program module was created to model the IRST system. Like the existing radar module, it transmits the contents of its current track files to the multisensor tracker at the end of each frame. Simple models for the infrared (IR) emissions of aircraft skin, tailpipe, and plume were created, and their input data added to the parameter list for each type of target in the simulation. In addition, models were set up for the IR surface and sky backgrounds, and for atmospheric attenuation. The general approach has been to match the level of realism in the IR model to that found in the radar model, which uses a Swerling model with a multipath correction factor for the radar cross section.

The modeling of the passive radio frequency (RF) sensor chosen for the demonstration was accomplished by adding code and input parameters to the existing radar simulation.

Two features enhance the usefulness of the simulation. The first is a simple measure of effectiveness for evaluating the effectiveness of the tracking algorithm. The function is inversely proportional to the average error between the track and the true target position, and directly proportional to the length of time for which the track is maintained. The second is the capability to generate output files containing time-tagged multisensor sensor data, and to replay these files later without the need to repeat all of the calculations of the simulation dynamics. The real-time computer system is being designed to accept these files as inputs when real sensors are unavailable. In addition, the simulation will be able to replay the data archived by the real-time system in tests with actual sensors. Figure 2a is a block diagram of the software modules used in the simulation, and Figure 2b shows the design concept which is being used to implement the interface betv en the simulation and the real-time system.

MULTISENSOR TARGETING ALGORITHM

As with the simulation, an existing software program was taken as the starting point for the development of the multisensor tracking algorithm. This was the Mission Avionics Sensor Synergism (MASS)/MINYAN algorithm developed at the Naval Air Development Center for the multisensor tracking of ships by surveillance aircraft. Although substantial changes were needed to adapt it to the air-to-... environment, it embodied the basic structure of a tracking algorithm, as diagrammed in Figure 3. The tracker consists ... basic functions:

1. The association function, which accepts the data provided by each sensor in turn and attempts to correlate it with existing multisensor tracks. If this is not possible, it creates new tracks. It also deletes old tracks if they have not been updated for a sufficiently long interval.

2. The update function, which combines the new data with existing tracks once the best matches have been determined. Kalman filtering is the technique used to implement the update function.

Agreement and branch-and-bound algorithms are employed as the central elements of the association function. Branch-and-bound is a standard mathematical technique for finding optimal solutions to search problems in minimum time. In order to use this algorithm, it is first necessary to define and calculate an agreement function that measures the likelihood that any one sensor detection is associated with any one multisensor track. The specific function used by this tracker is the chi-squared distribution function of the standardized difference between a multisensor track and a sensor detection. When a sensor completes a scan frame and delivers its data to the tracker, the values of this agreement function are calculated for all possible combinations of tracks and detections, and ...es are placed in an agreement matrix. Finding the set of one-to-one matches between rows and ... ...at ... ...e sum of the matrix elements for the set is thus equivalent to finding the most probable assign... ... detection... tracks.

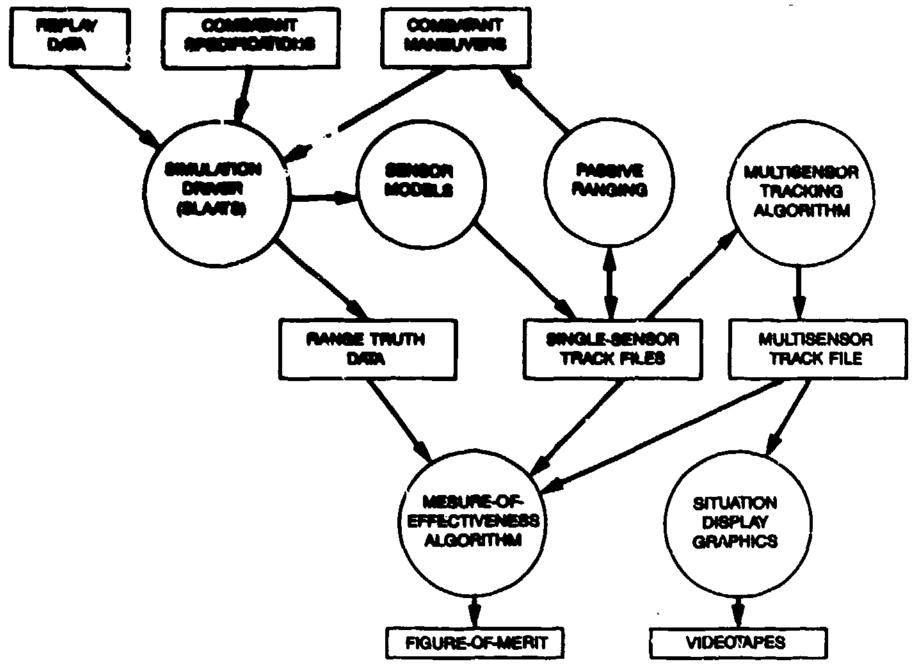

FIGURE 2a. Structure of Non-Real-Time Simulation.

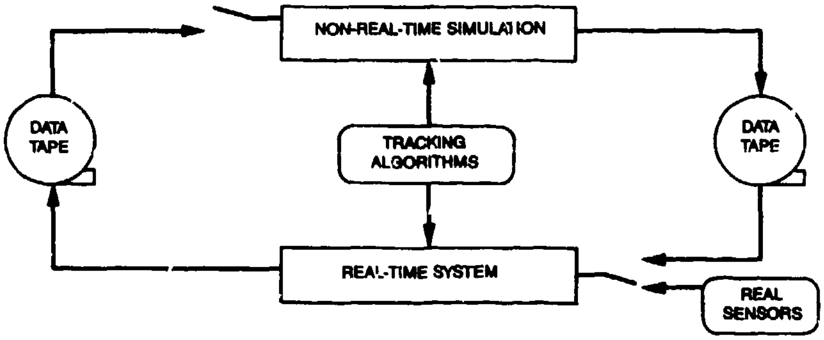

FIGURE 2b. Real-Time System and Simulation Interfaces.

The following is a description of the basic steps performed by the branch-and-bound algorithm in resolving ambiguities in the association of multisensor tracks and sensor detections.

1. Set up the track assignment problem as a decision tree.

2. Define a numerical measure for the goodness of all possible solutions, with the best measure being the one that is minimum.

3. At each point on the decision tree, determine a *lower bound* on the goodness measure if this branch is followed.

4. Use heuristics to determine the branch most likely to yield the best solution, and follow it to the end.

5. Explore other branches *only until* their lower bounds exceed the best value already found.

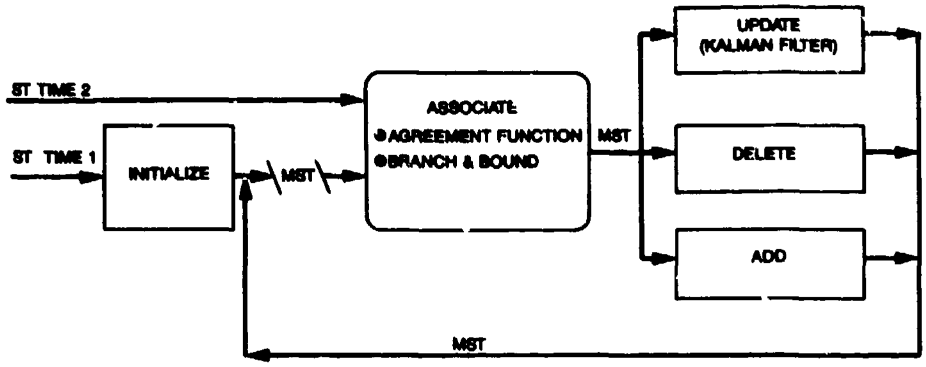

FIGURE 3. Generic Multisensor Tracker Functions.

The first modification made in the tracker was simply the conversion from tracking in two dimensions to three. The parameters of the Kalman filter in the track update function also were modified to reflect the vastly greater maneuverability of aircraft targets and the different resolution of the air-to-air sensors. Further modifications include the following.

1. An alternate branch-and-bound procedure, which cannot reexplore the same branch of the decision tree, was developed and substituted. The original branch-and-bound procedure could become trapped in an infinite loop if presented with multiple tracks occupying the same "region of confusion."

2. A clustering algorithm is being developed to modify the tracker to provide a capability to handle closely packed targets. The original association function viewed the track-matching problem as strictly a one-to-one mapping: one track can never match with more than one sensor detection, and vice versa. This property causes problems because of the mismatch in sensor resolution–between radar and IRST, for example. The radar cannot resolve multiple targets within a resolution cell, and so creates a single track for a closely spaced formation. However, the IRST has multiple detections for the same formation because of its superior angular resolution. The original association procedure would match only one of these detections with the radar track and leave the rest of them "dangling", unassociated with the radar data. Our solution is to preprocess the IRST data and cluster multiple detections occupying the same region of phase space into "raid tracks" with track coordinates given by the centroid of the individual tracks. The limits on the size of the clusters will be matched to the radar resolution.

3. The requirement of one-to-one correspondence between tracks and targets also causes difficulties for the case of multiple targets on converging or diverging courses. When a group of closely spaced targets, which are detected as a single track, approaches near enough to be resolved into individual aircraft, the present version of the algorithm creates new tracks that have no correlation with the track history of the original track. The reverse of the same process occurs when multiple individual targets come together to make a formation. The resulting single raid track does not preserve the track history of the merged tracks. A track history function most likely will be added to resolve this deficiency in the algorithm. As described, the current multisensor tracker has been designated the baseline for the development effort, and will evolve further as the program progresses and better understanding of air-to-air tracker requirements is gained.

The baseline multisensor targeting algorithm has been coded into the non-real-time simulation and is currently operational. An example of the performance level achievable by the baseline is illustrated by the plots in Figure 4.

These plots were generated by a graphics package acting on the output of the multisensor simulation. The graphics were designed as an engineering tool to aid algorithm development, and not as a tactical display simulation; however, they do demonstrate the problems involved in effectively interfacing multiple sensors with an aircrew. Figure 4a shows the true position histories of the targets in a typical simulation scenario: a five-aircraft formation passing obliquely across the field of regard of the multiple-sensor platform. In this scenario, the sensor platform is stationary, as under conditions of roofhouse testing. The simulation also permits a flying and maneuvering sensor platform. Figure 4b shows the instantaneous single-sensor track data when the targets are centered in the field of regard. Figure 4c contains the track histories generated by the multisensor tracker to be compared with the true trajectories in Figure 4a.

REAL-TIME SYSTEM

The hardware architecture of the real-time system, which will host the multisensor targeting algorithm for field testing and evaluation, is shown in Figure 5.

The system is built around a Rugged Digital VAX 11/751. The functions to be implemented in the VAX include: the acquisition of data from the sensor bus; preprocessing the data; hosting the multisensor tracker algorithm; displaying sensor/tracker data in real time; and archiving the data for later replay and analysis.

A RAMTEK 4225/4220 graphics processor pair will support both high-resolution colorgraphics display and low-resolution video recording of data in real time. Data archives will be maintained on a VAX-11/751 Winchester disk in real time, and on standard half-inch magnetic tape for long-term storage.

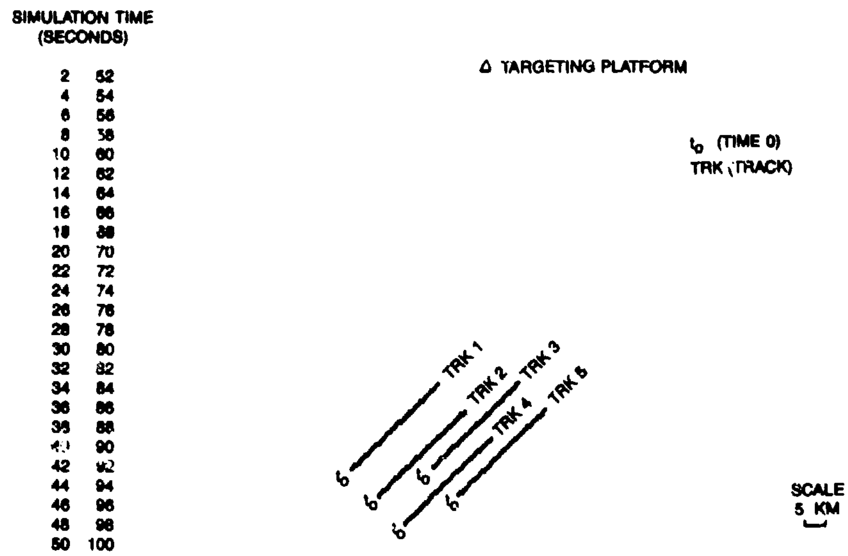

FIGURE 4a. Five-Aircraft Oblique Scenario, Track History, Truth Data.

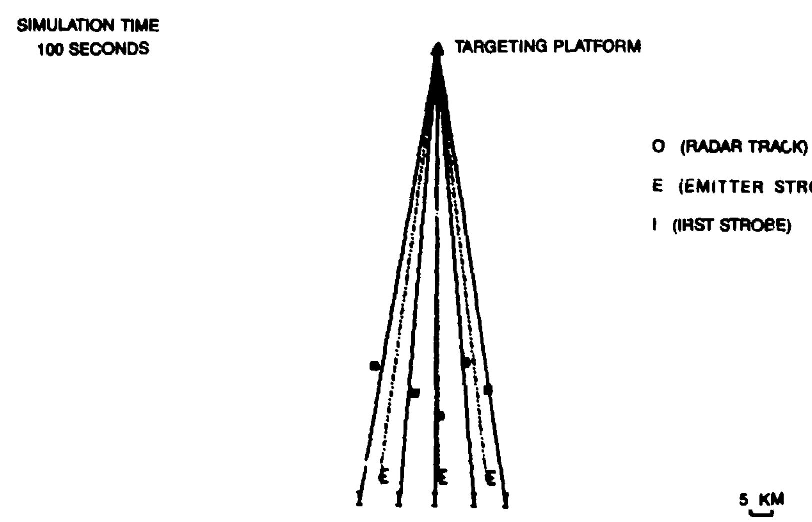

FIGURE 4b. Five-Aircraft Oblique Scenario, Single Sensors, Snapshot.

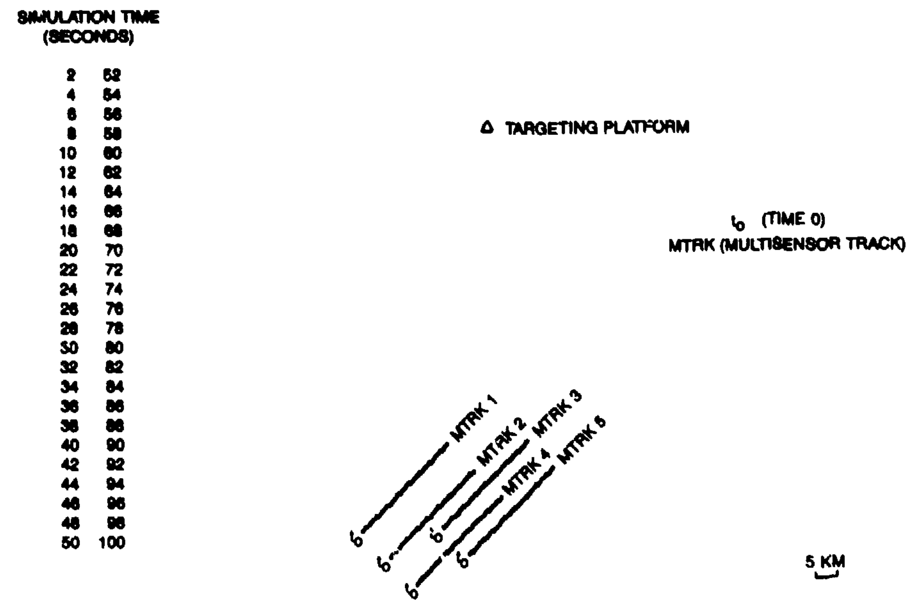

FIGURE 4c. Five-Aircraft Oblique Scenario, Track History, Multisensor Tracker.

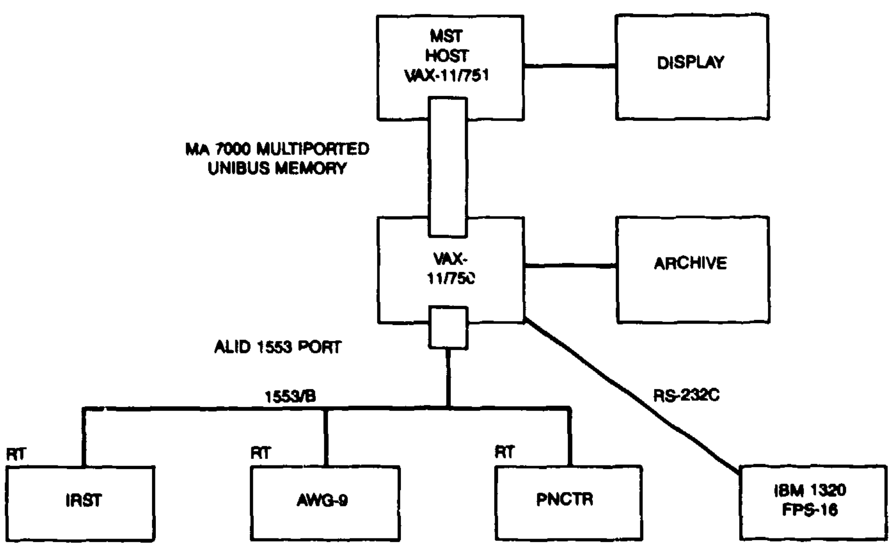

FIGURE 5. Real-Time System Hardware Architechture.

The data bus planned for the system is MIL-STD-1553/B which is supported at the VAX UNIBUS by an SCI Systems bus controller. RS-232C and RS-423A bus interfaces are also implemented to provide additional versatility. The 1553 interface with the host computer and the bus controller is implemented in an Avionics Laboratory Integration Device (ALID). The ALID device also includes a shared UNIBUS memory which allows a second VAX-11/750 to be interfaced with the system to add another half-MIPS of processing power.

The multisensor tracking real-time system software architecture is shown in Figure 6.

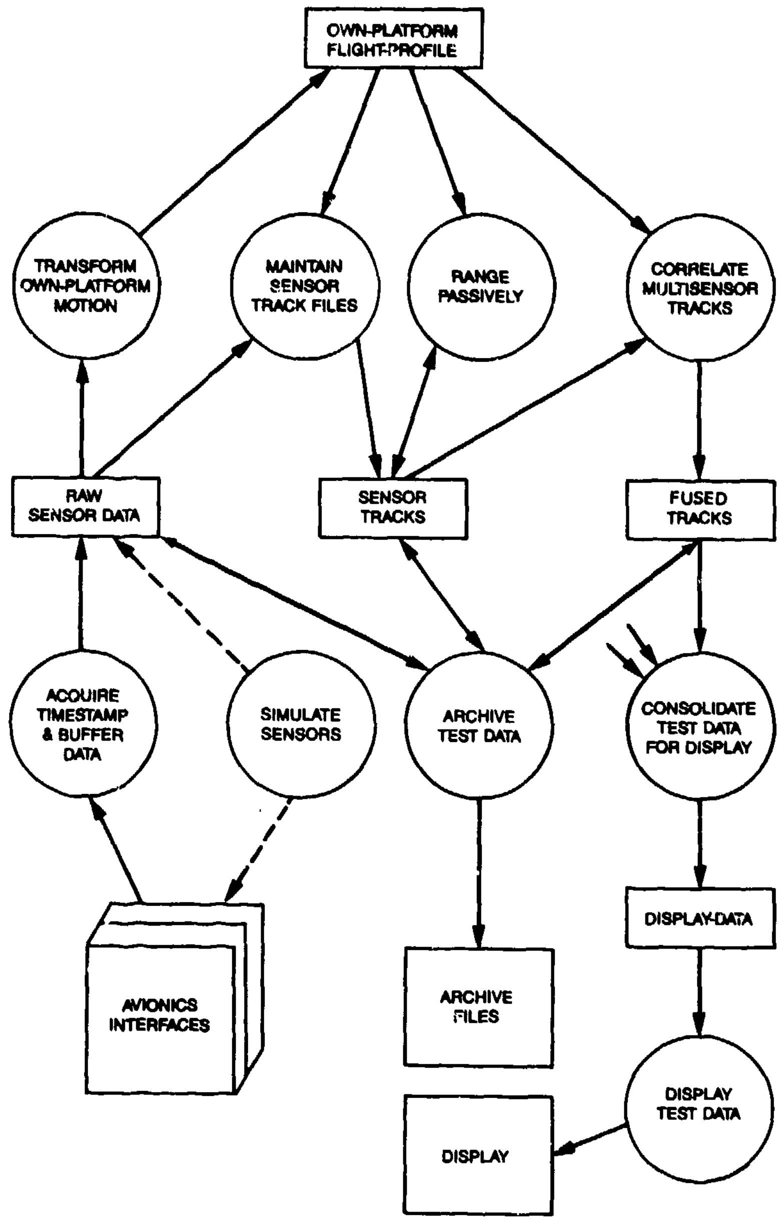

FIGURE 6. Real-Time System Software Architechture.

In addition to housing the MST algorithm, the real-time system includes support software modules that: interface the algorithm with the sensors; preprocess sensor data as necessary to support the demonstration; and archive and display in near real-time the demonstration test and evaluation results. The main feature of the system software architecture is a loosely coupled asynchronous system that runs under the VMS operating system. The software modules that make up the achitecture are as follows.

1. **SIMULATE_SENSORS** - provides a realistic, asynchronous model of the sensor data outputs and rates for driving the real-time system during development and debugging.

2. **ACQUIRE_TIMESTAMP_AND_BUFFER_DATA** - is the software module responsible for interfacing with the sensors to acquire data, to timestamp the data with system clock time, and to route the data to the appropriate RAM memory locations for use by other programs.

3. **TRANSFORM_OWN_PLATFORM_MOTION** - is responsible for processing target tracking data from range instrumentation and providing a pseudo inertial navigation system (INS) data store, designated (OWN_PLATFORM_FLIGHT_PROFILE). The data is available for input to the tracking algorithms. Also, the INS data can be manipulated by the TRANSFORM_OWN_ PLATFORM_MOTION program to make the stationary test site appear to be maneuvering, which is a requirement for the operation of the RANGE_PASSIVELY module.

4. **RANGE_PASSIVELY** - computes range estimates for the target aircraft based on own platform sensor angle-only and INS data.

5. **MAINTAIN_SENSOR_TRACK_FILES** - processes RAW_SENSOR_DATA using gating functions and KALMAN filtering to generate and maintain sensor tracks.

6. **CORRELATE_MULTISENSOR_TRACKS** - designates the multisensor targeting algorithm which will be hosted by the system.

7. **ARCHIVE_TEST_DATA** - is a series of programs that stores all real-time data on magnetic media for later replay or analysis.

8. **CONSOLIDATE_TEST_DATA_FOR_DISPLAY** - processes target position data from dissimilar data bases and uniformly formats them for access by the DISPLAY_TEST_DATA programs.

9. **DISPLAY_TEST_DATA** - implements interfaces with either a D.E.C. VT241 medium-resolution graphics terminal or a RAMTEK 4225 high-resolution graphics device for displaying multisensor targeting test and evaluation results.

The software architecture selected for the implementation of the real-time system is very flexible and versatile. Its loosely coupled, asynchronous design allows independent development and testing of the modules, and additionally will support major architecture modifications at a low incremental cost as the program progresses and for follow-on efforts.

The real-time system and the non-real-time simulation also are designed to enable the exchange of data between the two systems to expedite and support algorithm development and demonstration. A utility program is used in the real-time system to convert simulation output tapes to an acceptable format for input to the ARCHIVE_FILES module. A REPLAY_ ARCHIVE subfunction in the ARCHIVE_TEST_DATA module is capable of replaying the data into the real-time system in pseudo real time. Similarly, data can be transferred from the real-time system to the simulation by a utility that converts the ARCHIVE_FILES data to a modified simulation input format.

TEST PLANS

The real-time system will be installed in a roofhouse environment and tested and evaluated against flyover targets. A data feed from the range instrumentation radars will provide ground truth data against which sensor performance and multisensor tracker performance can be compared. Controlled target aircraft will then be flown in patterns within the field of regard of the colocated sensors. Patterns will be chosen to exercise critical aspects of the multisensor tracker (merging, splitting, centroiding, etc.) at ranges and altitudes that take advantage of optimum multisensor performance. The test ranges and altitudes of these scenarios are expected to be somewhat different from operational scenarios due to the ground-based nature of the demonstration. Data will be acquired and processed in real time in the field, after which the archive data will be returned to the laboratory for detailed analysis and to support further development/refinement of algorithms. Algorithm modifications made as a result of the laboratory analysis of the data base will then be added to the real-time system for evaluation in future field testing.

CONCLUSION

The MST program is the first phase of a long-range program to develop a fully automated targeting system for tactical aircraft, capable of processing raw sensor data for: target detection, identification, and tracking; controlling sensor modes; displaying targeting data to the aircrew; and passing data to weapon systems. Targeting sources to be integrated include radar; IRST; passive RF sensors; forward-looking infrared; identification, friend or foe; joint tactical information distribution system; etc. The realization of this long-range goal will depend on the successful development of an effective MST tracking algorithm.

The status of the current algorithm development effort is that a baseline multisensor tracker has been demonstrated in simulation. The tracker has successfully correlated data from multiple sensor inputs and provides smooth, well-behaved tracks under optimum conditions. Its performance can clearly be improved in several areas, and work will continue in this direction in the months ahead. A system architecture for the real-time demonstration of the algorithm has been defined and is currently being implemented. The requirements for testing and evaluating the algorithm are generally known, and testing is planned to start in about the September 1986 timeframe.

DISCUSSION

M. Stoll, France
If there is digital data transmission between A/C, you could consider correlating sensors which are not on the same platform. Have you worked in that direction?

P.G. Krueger
We have worked in that direction, addressing navigation accuracy requirements in relation to targetting accuracies desired. But that is not a part of this effort.

R.J. Scott-Wilson, UK
How well does the sensor fusion algorithm handle the occurrence of data arriving in a non-chronological order, such as from sensors with extreme differences in data rate?

P.G. Krueger
There is no particular problem. The algorithm as implemented, updates the correlated track file every two seconds, using data in the individual sensor's track files. If a sensor reports, say, every 10 update intervals, its data will be correlated with the other sensors' data when it arrives and integrated with the existing multi-sensor track file.

MACHINE ARCHITECTURES FOR ARTIFICIAL INTELLIGENCE COMPUTING

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Abstract

Alternatives to the von Neumann architectural model are under study by members of the advanced computer architecture community. Recent developments in multiprocessor technology can be shown to provide performance speed increases in the execution of expert systems. Several of these efforts have been followed closely and are assessed in this paper.

A predominant operation in AI programming is pattern matching. Searching a data base of K elements with a von Neumann architecture requires, at worst, O(K) steps. In the ideal case, a linear speed up is realized through the use of associative matching on a suitable multiprocessor system. Two multiprocessor systems that provide or simulate associative memory are DADO and ASPRO.

DADO is a binary tree machine under study at Columbia University. This topology was chosen owing to the simplicity of interconnection of the processors while keeping the number of intermediate points down in a worst case message passing setting. Furthermore, two-way branching in hardware provides flexible modeling of the problem domain. The forward chaining production system model maps quite naturally onto this architecture. Indeed, a linear speed up over execution on a sequential machine is conceptually realizable. This is gained by making the match phase a fully parallel activity.

While DADO is a multiprocessor system designed with AI applications in mind, Goodyear Aerospace Corporation's ASPRO™ was found to be an existing architecture that is suited to the task of eliminating the match phase bottleneck. ASPRO is a nearest neighbor bit-wise associative architecture that can also provide linear speed up during the matching phase.

Both multiprocessors are fine grain, having many processing elements, each with a small local RAM (Random Access Memory). As such, they quite naturally are able to perform associative matching. They both have a problem when there is need for procedural intervention during the execution cycle. ASPRO would have to handle a multiplicity of such requests sequentially on a 16-bit processor. DADO has a small processor locally available to each rule for procedural intervention. ASPRO, on the other hand, requires fewer processors than DADO to achieve the associative memory effect. Both processors have potential communications bottlenecks. ASPRO, which operates in strict SIMD (Single Instruction Multiple Data) mode, does not have the need for synchronization required of DADO when it performs matching while in MIMD (Multiple Instruction Multiple Data) mode (3).

Bolt Beranek and Newman's Butterfly™ multiprocessor is a coarser grain machine that has fewer processing elements, each with much more memory (up to 4 MBytes). The associative matching schemes of DADO and ASPRO would not fit this architecture directly. An advantage of Butterfly is realized when there is a need for procedural intervention, since it could be easily handled using a M68000 processor and a large local RAM.

Thinking Machine Inc.'s Connection Machine™ represents a unique type of multiprocessor in that the processing elements are dynamically reconfigurable and are of fine granularity. As such, it can be made to resemble ASPRO and DADO. It can also be used to experiment with other possible topologies.

In this paper we will expand on the points made in the abstract and add further considerations which include: availability, suitability to various inferencing schemes, development tools, and host processor possibilities.

1.0 Introduction

For over three decades software systems have been designed to run optimally on the pervasive von Neumann computer architecture. Various general and special purpose software/hardware systems have evolved. Recent developments in computer hardware have resulted in the emergence of alternative, multiprocessor architectures. New approaches to software systems that outperform their von Neumann counterparts are also emerging.

Concurrent with the evolution of computer architecture has been the independent development of the field of Artificial Intelligence (AI). More recently, several AI systems have been demonstrated to be capable aids to humans in making difficult deci-

sions. Perhaps the best known of these have gained recognition in the area of medical diagnostics.

Fueled by DARPA and other government agencies world-wide, there has been much recent interest in using AI to develop aids for the planning and execution of military operations. As developing AI systems were tried on von Neumann processors their performance has been found to be too slow for them to be viable in many military and real time applications.

One reason that AI systems perform poorly on von Neumann architectures is because they must repeatedly cycle through many memory locations and process them sequentially. Accessing and processing one memory unit at a time is the nature of the sequential von Neumann machine but not necessarily the nature of the AI system. We are thus led to a general requirement for alternative architectures which are suitable for AI system execution, namely, that they provide parallel access to many units of memory and the ability to process each unit concurrently.

Some memory accesses and associated processing may trigger procedure calls. This would cause even slower execution in the sequential execution model. Performance in the parallel scheme will be affected by the number of processors that are available. In the worst case, only one processor handles all procedure calls. This causes another form of performance bottleneck--where all memory units have been accessed but a queue of procedure calls is being handled by a single processor. Accordingly, another general requirement of AI machine architectures is that they be able to provide procedural-level parallelism.

It would appear that assigning one processor per procedure call would solve this problem. However, it may occur that various procedures require multiple access to a shared resource. This is a third potential bottleneck and introduces another design requirement.

The above discussion represents some of the issues involved in the execution of AI systems that should be kept in mind when evaluating hardware. To compound the situation further, AI systems are continually changing. An architecture that works well for today's system may not handle the evolving systems of the future.

There are many multiprocessor architectures proposed for different non-AI applications, and it is not apparent which architectures, if any, optimally support AI systems. In this paper we shall provide examples of current AI architectures and illustrate how they handle the issues raised above. We conclude with a recommendation on how to proceed with the selection process.

2.0 Machine Architectures Past and Present

2.1 The von Neumann architectural model has a single processor connected to memory by a communication bus. The bandwidth of the communications link limits system performance.

```
                   BUS
| MEMORY | -------------- | PROCESSOR |
```

Figure 1 von Neumann Architectural Model

The model illustrated in Figure 1 is the classical model for sequential computing. Here one unit at a time can be transferred between the store and the CPU and hence, one unit at a time can be processed.

This model made sense when the memory was of a different technology than the processor, for example, ferrite cores versus discrete transistors. Today, however, memories and processors are made out of the same silicon. As such, alternative architectures are possible. With today's (VLSI) technology we now have the capability of providing one or more complete processors with their own local memory on the same chip. The term processing element (PE) is used to refer to a processor and its associated local memory.

3.0 Nature of AI Computing

We envision that candidate AI systems for aiding in the planning and execution of air warfare and ground strike operations will incorporate knowledge through rules and data structures. As a fundamental activity, external inputs will be integrated with known data to form an upgraded set of facts on which to operate. These facts will be used to draw inferences which lead to further updates to the accumulating facts. All of this activity, if it is to be of any real use, must be accomplished quickly.

The production system (PS) formalism is widely used to model such systems. This is because the PS model is reactive to change since all data, including new inputs from sensor readings and inferences, is considered immediately for the next system update cycle.

We present an overview of the PS formalism. Then we explain how traditional computer technology limits run time performance of this model. We follow with an explana-

tion of how speed up can be achieved by taking a forward look at possible next-generation AI machine architectures for PS execution.

4.0 Production System Overview

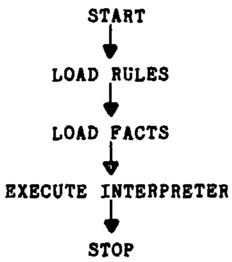
A PS consists of three components: rules, facts and a rule interpreter. The rules are logical expressions in the form: IF antecedent THEN consequent. The antecedent is of the form $A1 \wedge A2 \wedge \ldots \wedge Ak$ where the Ai $(i=1,\ldots,k)$ are the conditions under which the rule will fire or become activated. The consequent is of the form $C1 \vee C2 \vee \ldots \vee Cm$ where the Cj $(j=1,\ldots,m)$ are alternative conclusions that the firing of this rule leads to. Oftentimes $j=1$. The facts are in the same form as the rule antecedent conjunction elements, Ai and consequent disjunctive elements, Cj. The rule interpreter is a three phase loop that repeats until the system is halted. The three phases are the match phase, selection phase and the action phase.

As an example, suppose we have the rule IF (A/C IN COMMERCIAL AIRLANE) $\wedge$ (VELOCITY 1120 KM/HR) then (A/C IS POTENTIALLY NON COMMERCIAL) $\vee$ (CHECK VELOCITY SENSOR). Here we assume that commercial aircraft fly at velocities $\leq$ 1120 KM/HR.

Suppose that we already know the fact that A/C IN COMMERCIAL AIRLANE due to prior monitoring. At such time when the velocity increases to 1120 KM/HR or more this rule is able to fire.

4.1 PS initial load and execution cycle

The following flow diagram captures the startup and execution of a production system (7).



Execution of the rule interpreter consists of repeating the loop illustrated in Figure 2.

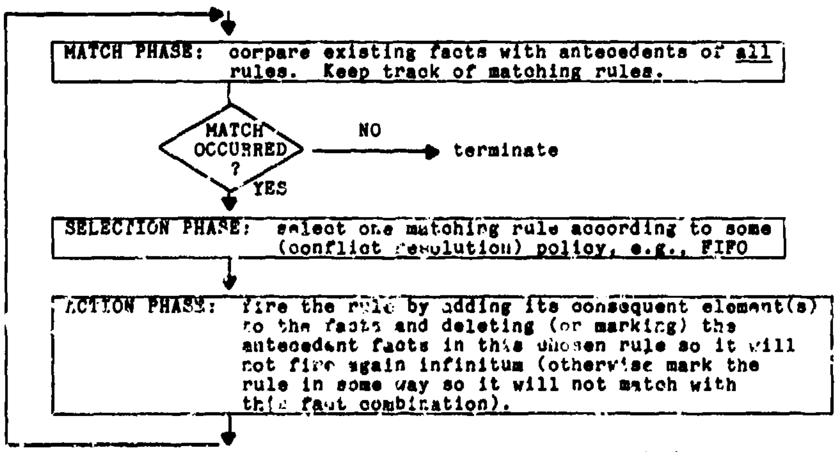


Figure 2 PS Rule Interpreter

4.2 PS execution performance in general

Experience has shown that about 90% of the computing time in PS execution is spent in the match phase with the rest of the time divided evenly between the conflict resolution (selection) phase and the action phase (4). Since the execution is dominated by matching, we will focus on the execution of this phase in this paper.

4.3 Matching von Neumann style

Suppose the PS has R rules and F facts. The match phase involves comparing the left hand sides of all rules to see if they match the current facts in working memory. Suppose the rules and facts are stored as follows:

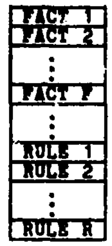


Figure 3 Rules and Facts in Memory

To match rule I ($1 \leq I \leq R$) would require the CPU issuing fetch instructions to bring rule I into its processing registers, then fetching facts until either a match occurs or all facts have been tried. We shall refer to this activity as match cycle. Since all rules are to be matched, R match cycles are required during the match phase of each production system execution cycle. Figure 4 illustrates the PS execution cycle from the serial viewpoint we are describing.

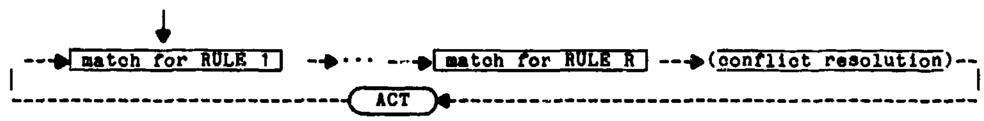


Figure 4 PS Execution (Serial Viewpoint)

In the above scheme, while the left hand side of the rule I is being matched, rules 1 through I-1 and rules I+1 through R are sitting idle. Either they have been processed or are waiting their turn. Many enhancements have been implemented as an aide in speeding up this process, namely, pre-fetch strategies, caching and pipelining. Even to the degree of producing supercomputer level performance, what remains is a bottleneck where rule I is matched before rule I+1.

What does this mean in terms of execution speed? Studies have shown rule firings in the range of 1 every 3 seconds to about 60 firings per second (4, 6). If AI systems are to be fieldable they must be made faster.

4.4 Match phase parallelism - a generic view

Matching can be handled in parallel by dividing the rules into several partitions and performing the match for each partition in parallel. An upper bound on this would be to have the number of partitions equal to the number of rules in the system. In this case the match for each production in the system is done in parallel. System execution can now be viewed as follows (4):

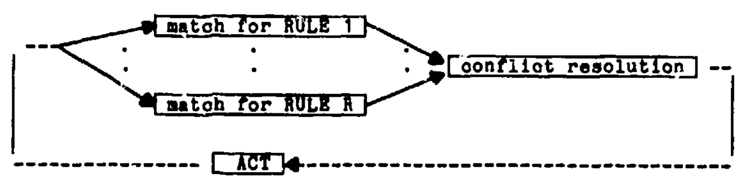


Figure 5 PS Execution (Parallel Viewpoint)

In the above design R rules would be matched on R processors. The best speed up expected is a factor of R (2). Such a matching scheme can be accomplished using a content addressable memory.

5.0 Next generation machine architectures

Using multiple PEs we are able to implement an associative memory in which we simultaneously access the content of R memory locations in parallel. We can have R PEs, each waiting for a signal from a controller PE to access their local memory. When that signal is received they perform an operation on their local RAM. Using this scheme we can have parallel match phase execution where the local operation performed is to match a rule that is stored in the local RAM against facts that are also available locally.

Ideally one can realize a linear speed up in the match phase, and thereby achieve a substantial increase in execution speed of the PS execution cycle (2).

Many schemes are possible for configuring multiple PEs, and a great deal of current research is devoted to finding suitable architectures for AI computing. We present an overview of two candidate systems which we have chosen since they allow for associative matching. As part of our overview we shall show how the PS model maps onto the architecture. We shall follow with a view of two other multiprocessors, then compare and contrast the four.

6.0 DADO

DADO is a multiprocessor system under design and development at Columbia University (7). The PEs are arranged based on a complete binary tree. The first prototype, which has been operational since 1983, has 15 PEs, one per binary tree node. Each PE has 8-16K of local RAM. The next prototype will have 1023 nodes or PEs and should be operational this year. Future plans call for 100,000 PEs.

6.1 An overview of the DADO machine architecture

Within DADO each PE can execute in either SIMD or MIMD mode. In SIMD mode the PE executes instructions which are broadcast by some ancestor PE within the tree. This mode, for example, would be used when loading information into the tree. In MIMD mode each PE executes instructions stored in its own local RAM. This allows a PE and its descendents to be disconnected from the rest of the tree. In this way the tree can be partitioned into logical processes. The MIMD PE may broadcast instructions to be executed by its own descendents provided they are in SIMD mode. This combination of MIMD/SIMD supports the logical division of the machine into distinct partitions, each executing a distinct task. The root node of the entire tree would be a conventional processor acting in MIMD mode (e.g., a VAX) which controls the operation of the ensemble of PEs.

6.2 Production systems on DADO

6.2.1 Loading the system

Suppose there are R rules in the PS. Select the level in the tree having at least R nodes (PEs). We refer to this level as the PM level (for Production Memory). Load one rule per PM level PE so as to achieve maximum parallelism. As a result, each rule can be matched simultaneously. At the same time load a copy of the matcher into the PM level PE's local RAM. The PEs located below the PM level are referred to as the WM (for Working Memory). The WM level PEs will be loaded with facts. Since rules are loaded first we can use their left hand sides to filter the facts as they are broadcast downward. In this way only relevant facts are associated with each rule. The result of the initial load can be visualized as follows:

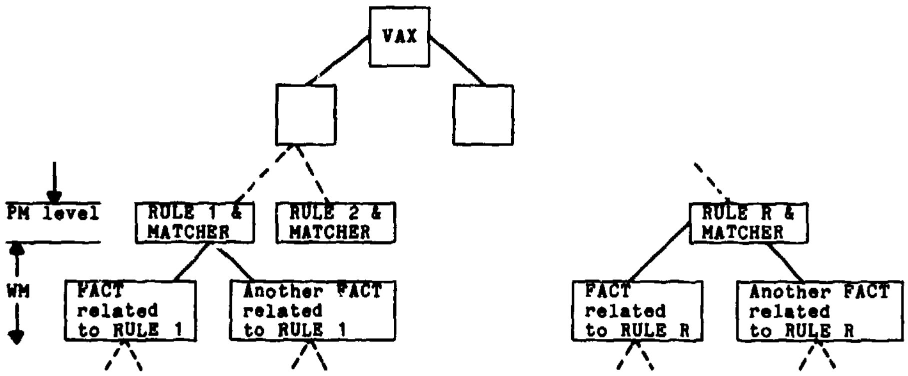


Figure 6 R rules and F facts on DADO

6.2.2 PS execution on DADO

Once the system is loaded, the PS can go into its inferencing cycle. A new fact is broadcast by the host (root) PE to the PM level PEs which are in SIMD mode. In lock step they switch over to MIMD mode and proceed to execute the match phase-- all rules have their left hand sides matched in parallel. The time to perform the matching is independent of the number of rules. When the matching phase is over, processors having matching left hand sides will have flags raised. One rule is selected from among those that match. This selection will be made according to a standard strategy, such as the recent activity of the system. The facts on the right hand side will be passed up to the host which will, in turn, broadcast them to the PM level PEs which are again in SIMD mode. This process continues recursively.

6.2.3 Performance

In an ideal case where each PM level PE contains 1 rule as we have just described, we can realize a linear speedup in match phase execution. In a system with R rules the conventional machine requires R match cycles, while this scheme requires 1.

7.0 ASPRO

Unlike DADO, which was designed with production systems in mind, Goodyear Aerospace Corporation has found their ASPRO multiprocessor to be an existing machine that is highly suited to speed up of the match phase of PS execution (5).

7.1 An overview of ASPRO

It is easiest to think of ASPRO as an array of 2048 SIMD PEs each having 8K bits of local RAM and 3 registers X, Y and M. ASPRO is a bitwise processor where the bit being processed is at the intersection of a bit column window and a bit row window.

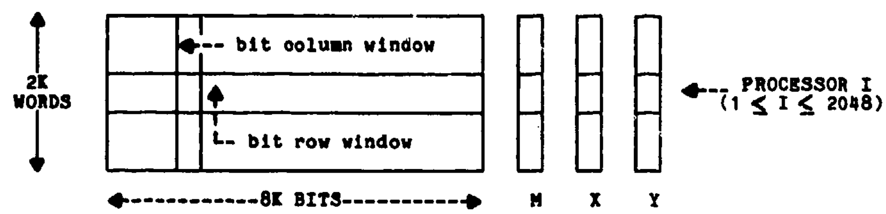


Figure 7 ASPRO (General View)

A row of bits, or some portion, is accessed by advancing the bit column window while holding the bit row window fixed. A column of K bits is processed by fixing the bit column while employing the corresponding K processors. Any of the 16 Boolean operations can be performed.

7.2 Production system implementation on ASPRO

In the following discussion we shall assume an F fact/R rule system.

7.2.1 Fact base

The F distinct facts are either known or are inferrable from right hand sides. These are stored in a dictionary of F entries. The position of a fact places it in unique correspondence with the natural numbers 1 through F. As an example, consider the 4 facts which appeared in the rule we presented in Section 4.0. Figure 8 shows these stored at locations 1, 2, 15 and F in the fact dictionary.

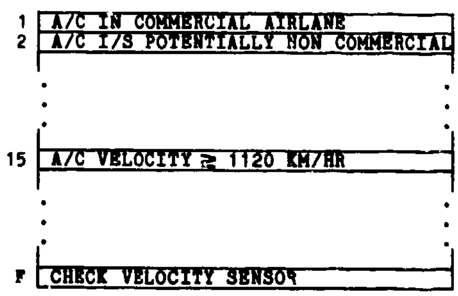
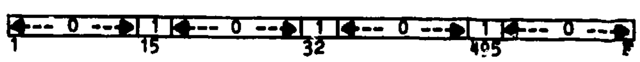


Figure 8 ASPRO Fact Dictionary

The dictionary is stored in the processor memory.

7.2.2 Rule encoding (IF-part)

Any of the F facts may appear on the IF-side or THEN-side of any rule. An F-bit map is sufficient to encode each side of any rule. For example, suppose facts 15, 32 and 495 appear in the IF part of a rule (assuming $F \geq 495$). This can be encoded as follows:



To obtain the actual facts the system is required to look up entries 15, 32 and 495 in the dictionary.

7.2.3 Rule layout in memory

The IF-parts are stored in an R word by F bit partition in memory. The first word corresponds to the F-bit encoding of the IF-part of rule 1 and so on. The THEN-parts are stored in a separate F by R block. Here the first F-bit column corresponds to the THEN-part of rule 1 and so on.

In Figure 9 we show how the sample rule of Section 4.0 would appear in the memory.

The F bits of the X register are used to keep track of the current facts in the system.

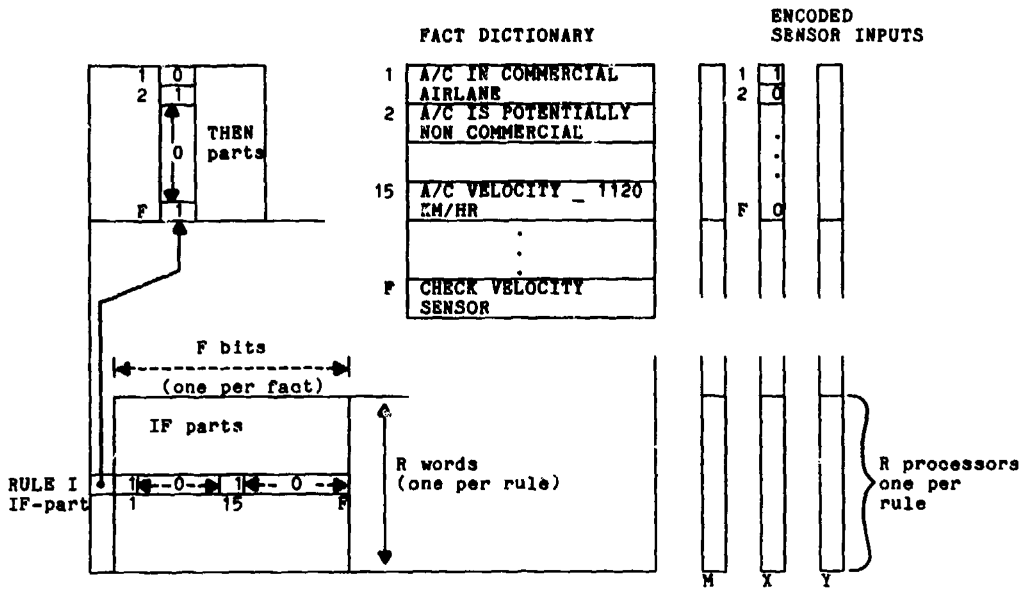


Figure 9 A sample rule on ASPRO

7.2.4 PS execution on ASPRO

Suppose sensor readings indicate that A/C IN COMMERCIAL AIRLANE. If nothing else is known, this will be encoded as follows:

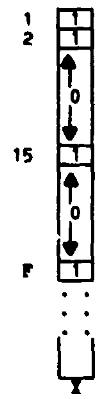
1 | ←--- 0 ---→
1 2 F

These F bits are loaded into the X register and represent the initial state of the current facts. This portion of the X register is matched against all rule IF parts. In this case, the Ith rule does not match owing to bit 15.

Subsequent sensor reading may detect the additional fact that the A/C VELOCITY ≥ 1120 KM/HR which is encoded as:

1 | ←---- 0 ----→ | 1 | ←---- 0 ----→
15

Now the IF part of rule I will match. When the rule fires a pointer is followed to rule I's THEN-part. The F bit column vector used to encode the consequents is added to the current facts in the X register by performing an OR operation. This results in the following updated status of the current facts in the system:



Four facts are now known, two were brought in by sensors and two were inferred as a result. The inferencing cycle continues recursively.

7.2.5 Performance

Current facts stored in the X register can be matched against the IF-parts of all R rules in 1 match cycle. The first bit of all R rules is checked against the first bit in the X register, then all second bits are checked and so on through bit F. Again we observe a parallel processor that is able to match all R rules concurrently.

8.0 Butterfly

Bolt, Beranek and Newman's (BBN) Butterfly is a MIMD multiprocessor where each PE has a full 32-bit processor and at least 256K bytes of local memory. As such, each PE provides far more computing power than those in either DADO or ASPRO. Currently the Butterfly comes configured with 1 to 256 M68000 PEs which can be expanded to contain from 1 MByte up to 4 MBytes of local RAM. The memory is shared among all the PEs. This is accomplished by allowing any PE to reference the local memory of another via a switch (1).

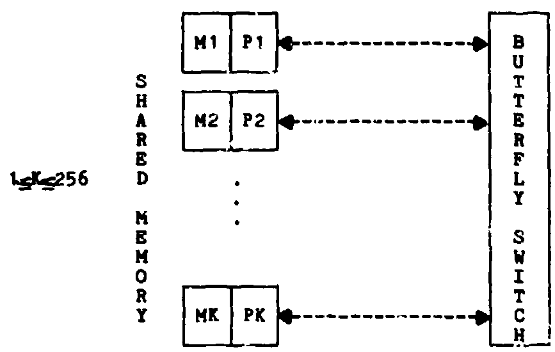


Figure 10 Butterfly (General View)

The Butterfly can simulate single processor von Neumann as well as SIMD architectures. However, the associative match schemes that mapped naturally onto DADO and ASPRO would be lost here. Several rules would be distributed across the PEs when rules outnumber the PEs. Actually, having several rules per PE might be suitable. As AI systems grow larger they are likely to be partitioned into subsystems themselves, consisting of groups of related rules. The related rules could be distributed across the Butterfly PEs. The shared memory would provide a facility for communications. Unfortunately, there has not been much work done at BBN on the suitability of the Butterfly to the execution of Production Systems.

9.0 Connection machine

Thinking Machines Incorporated has produced the Connection Machine. Currently this is a 64K PE SIMD, software-reconfigurable multiprocess system. Each PE has 4096 bits of RAM. The associative match schemes of DADO or ASPRO are each able to be mapped onto this architecture. So are multitudes of other schemes, since the PEs are able to be logically connected into whatever pattern best suits the application. A PE can be connected to any other, at any time, by simply storing the address of the second in an appropriate register in the first. The reconfiguration can occur at system set up time and dynamically at run time (8).

10.0 Assessment

So far we have viewed four multiprocessors as potential pattern matches. We shall now provide a broader assessment.

10.1 Positive attributes

DADO

- The tree architecture partitions easily into logical processes and naturally models the forward chaining PS formalism.
- Area efficient construction on a silicon chip couples with the fact that the number of pin-outs remains constant no matter how densely processors are embedded on the chip. This demonstrates a potential for full VLSI implementation.

ASPRO

- A U.S. mil spec'd version now exists.
- The 2048 PE system occupies 8"x10"x9.5" and weighs only 37 pounds.
- PS formalism maps onto SIMD architecture quite naturally.

BUTTERFLY

- DADO 1 has been implemented using an 8-bit INTEL chip; ASPRO has a 16-bit processor available for procedural processing. Butterfly offers a considerable advantage since a 32-bit M68000 with at least 256 KBytes of RAM is available in each PE. If some numerical processing is also required local to PE activity the Butterfly is better equipped to handle it. An example of where this might occur is when CHECK VELOCITY SENSOR is the result of a rule firing. To accomplish this a FORTRAN subroutine might need to be executed locally.
- The software for the Butterfly is more mature than that of the multiprocessors considered in this paper since BBN has been developing it over the past 5 years while the others have only 1 or 2 years of investment.

CONNECTION MACHINE

- This multiprocessor is dynamically reconfigurable. As such it provides a very useful tool with which to study the different architecture topologies most suited to various applications.

10.2 Negative attributes

DADO

- There is a potential communications bottleneck at the top of the tree.
- Each PM level PE must be synchronized on every process, and many may be idle waiting for slowest PEs to finish.
- DADO is not mil spec'd.
- The PEs between the root PE and the PM level are used sparingly for communications mainly. They are sitting idle during the match phase.

ASPRO

- When the application allows procedural intervention as part of the control strategy, ASPRO would schedule its 16-bit sequential processor. When several rules involve procedure calls, a bottleneck would exist.
- ASPRO would perform poorly anytime the system has to be reloaded, as is the case when the number of rules exceeds the capacity of the system. Some rules would be paged to disk, causing an appreciable slowdown.
- A factor that must be considered is the amount of time it takes to convert raw signal data into encoded form. This may be a serial task and the source of another possible bottleneck.

BUTTERFLY

- Butterfly is not mil-spec'd.
- There is currently no file system; system loading is a slow process.
- Granularity may be too coarse for some systems.

CONNECTION MACHINE

- Its newness
- Availability
- Not mil spec'd
- Procedural intervention would be handled on the host processor and thus may constitute a potential bottleneck.

11.0 More comparisons

We shall now consider each multiprocessor with regard to availability, suitability to various inferencing schemes, development tools, and host processor possibilities.

DADO

- Host Processor - VAX 11/780
- Host Language - Assembly Language, PL/M; PROLOG, LISP, OPS5, HERBAL are under study.
- Development Tools - Undetermined
- LISP Suitability - Under study
- Inference Engine Suitability - Rule based system, logic programming
- Expandability - 15 processors DADO 1 since 1983; 1023 Processors DADO 2 end of 1985; 100K processors proposed.
- Physical Size - DADO 1 is roughly the size of an IBM-PC
- Rule Capacity - small for DADO 1
- Availability - University Research Machine

ASPRO

- Host Processor - PDP 11/34 (VAX 11/780 soon)
- Host Languages - Assembly language/FORTRAN
- Development Tools - none
- LISP Suitability - Under development
- Inference Engine Suitability - Rule based system
- Expandability - Capable of expansion beyond current 2K processors
- Physical size - 8"x10"x9.5", 37 lbs.
- Rule Capacity - 2K rules
- Availability - Currently available, fielded in an E2-C environment

BUTTERFLY

- Host Processor - VAX 11/780 or Sun workstation (Symbolics 3670 soon)
- Host Languages - C
- Development Tools - Unix tools
- LISP Suitability - MultiLISP currently implement; major effort to port parallel LISP
- Inference Engine Suitability - Undetermined
- Expandability - 1-256 processor nodes are possible
- Physical Size - Standard cabinet
- Rule Capacity - Undetermined but larger than ASPRO
- Availability - Currently available

CONNECTION MACHINE

- Host Processor - Symbolics 3670

- Host Language - CMLISP
- Development Tools - Symbolics environment
- LISP Suitability - Primary language
- Inference Engine - Various
- Expandability - 1-64K processors can be virtually configured
- Physical Size - Standard cabinet
- Rule Capacity - 64K plus
- Availability - End of 1985 for 64K model

Conclusion

The authors They

~~We have~~ pointed out several issues that should be considered as part of an evaluation of potential AI machine architectures. ~~We~~ have then exemplified several activities of the advanced architecture community that focus on improving the run-time performance of AI systems. One can conclude that when the architecture matches the algorithm, the performance increase is substantial over that of von Neumann architectures. For example, when ASPRO is given an exact match forward chaining production system to execute, the performance increase is linear over von Neumann. If that same machine architecture were presented many procedure calls during execution, performance would degenerate to that of a sequential architecture.

Real-time AI system designers should address the issue of matching their algorithms to machine architectures from the beginning of the system development process. The higher the real-time performance requirements become, the more critical this ongoing evaluation becomes.

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NEW TECHNOLOGY IMPACTS ON FUTURE AVIONICS ARCHITECTURES

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SUMMARY

This paper provides an interpretation of avionics architecture with respect to system components, organization, and design factors. Initially, general avionics architecture characteristics are addressed followed by discussions on emerging new technologies and their impact on advanced systems. Information handling requirements are projected for future tactical aircraft. In addition, advanced avionics architecture design consideration and technical issues are addressed relative to achieving improved performance, reliability, survivability, flexibility and low life cycle cost.

ARCHITECTURE - AN INTERPRETATION

Although the term "architecture" is subject to interpretation, it generally applies to system design characteristics such as implementation, structure, organization, and performance. This implies the design of specific building blocks, the interconnection of building blocks, and the dynamic interactions and management of building blocks which control the behavior of a system.

As related to avionics, a system consists of the combined electrical, electronic, and physical integration of those on-board subsystems required to perform the operational functions of the stated mission of the aircraft.[1] Figure 1 depicts a simplified diagram of a typical avionics suite consisting of three major subsystems interconnected by means of a communications network to form an architecture. A sensor suite generally consists of equipment that enables external information (e.g., navigation, communications) to be acquired for use by the system. A processing subsystem provides the necessary mission processing, coordination, and information distribution functions. A displays and controls subsystem provides the vital link between the operators and the system.

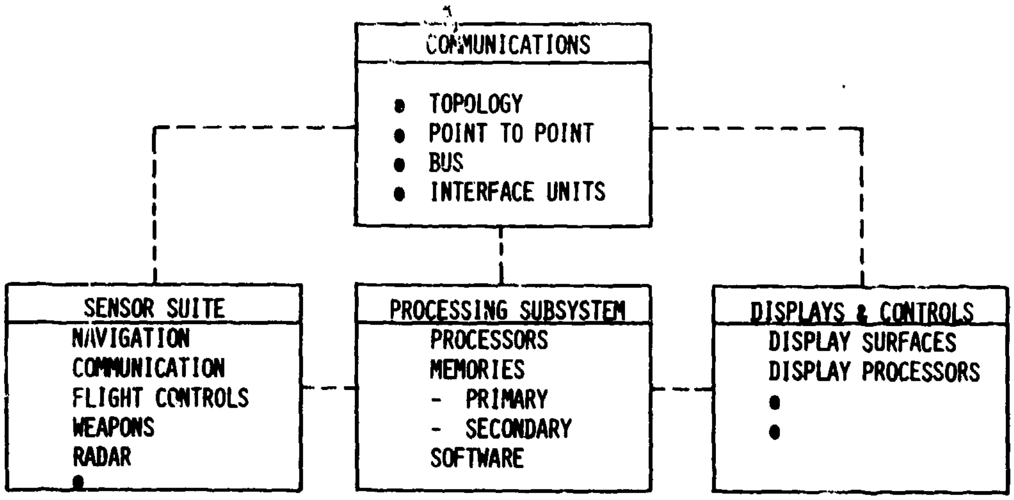

Figure 1. Simplified Avionics Model

There are numerous ways of configuring an avionics system where a particular architecture results from various design and programmatic considerations and constraints. This implies that all system design objectives must be optimized to the degree possible within these constraints.

To illustrate some of the practical aspects associated with the design of an avionics system, consider the alternatives involved with the processing subsystem in Figure 1. The major considerations to be addressed are shown in Figure 2.

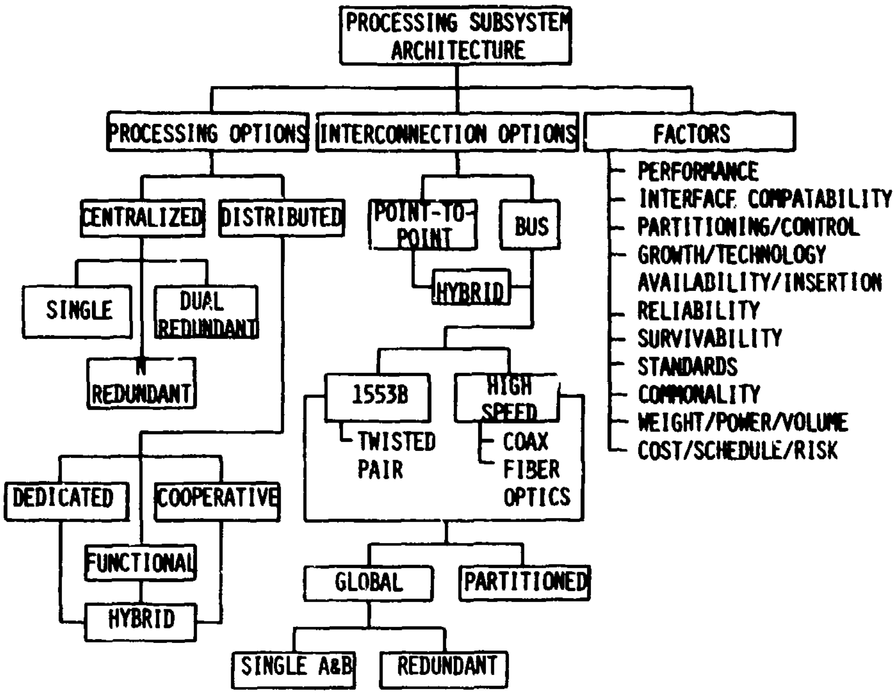

Figure 2. Design Considerations/Trade-Offs

Processing Options

There are several general approaches that can be considered for avionics processing. The traditional approach is centralized processing. This implies that all processing functions reside within a single processing element. Alternatively, for increased reliability, a back-up or redundant processor could also be provided in the event the primary processor fails and is typically referred to as the dual redundant approach. However, dual redundancy is still a centralized approach since the processors are identical both in hardware and in software. For this approach to be viable, provisions must be made for detecting, confirming, and recovering from a processor failure. Other variations of the centralized approach to incorporate higher degrees of reliability can be referred to as N-redundant processing.

Another approach that is currently gaining impetus is distributed processing. The objective of this approach is to find methods of improving performance by creating systems which exploit parallel, concurrent, or simultaneous execution of tasks by using multiple processing elements. There are many claimed potential benefits of this approach which include improved performance, reliability and expandability. One of the problems, however, is that there are currently no uniform interpretations or standard approaches to applying distributed processing in general, let alone in the military. One way of viewing the variations in distributed processing is by specific methods of application which include dedicated, functional, and cooperative. Dedicated implies that a processor is specifically associated with or dedicated to a particular equipment or system function. Functional implies that system functions are grouped or partitioned in a manner that these groups are assigned to specific processors. Cooperative implies that several processors collectively or cooperatively perform the necessary processing functions.

Interconnection Options

Figure 2 characterizes the basic types of interconnection options available for connecting avionics system elements. Point-to-point connections are employed for directly connecting equipments by means of dedicated links. These could be either parallel or serial. Since point-to-point connections tend to increase wiring complexity as well as overload processor I/O channels, systems are converting to bus oriented architectures. However, systems typically are never completely bus oriented and require certain selected point-to-point connections. The reason for this is that for certain critical functions, where bus latency is intolerable, a direct connection may be required. Another reason is that interface changes to existing equipment to accommodate the bus may be cost prohibitive. Bus bandwidth limitation is also a factor. Consequently, what usually results is a hybrid consisting of both bus and selected point-to-point connections.

From an architectural point of view, bus organization could be either global or partitioned. Assuming the 1553B philosophy of using a redundant pair, a global bus implies a single path is provided for communicating with all associated resources. Redundancy could also be provided as back-up by adding another pair of busses, where a global or partitioned scheme could be employed.

Another approach that could be used is referred to as partitioned global busses. This implies that several bus pairs could be provided for simultaneous or concurrent use so that collectively a higher bus bandwidth could be achieved. For example, if two 1553B bus pairs at 1 MHz each are employed, the combined bandwidth would approach 2 MHz. This approach requires that the system equipment be functionally partitioned so that the bus traffic is proportionately distributed. Schemes could also be devised such that the loss of either bus pair would not result in a system failure by appropriate equipment distribution on the busses.

Other Factors

Other factors that influence the design of a processing subsystem architecture are shown in Figure 2. They are typical of any military system and are both technical and non-technical in nature. This implies that trade-offs are constantly being made to optimize and balance a design to the degree possible within the constraints of a particular program.

ADVANCED AVIONICS

Estimates for future tactical aircraft indicate the need for at least an order of magnitude increase in avionics integration when compared to present systems. Countering threats in a dense electronic countermeasures and a night/adverse weather environment imposes difficult real-time constraints to accurately represent constantly changing situations. Future tactical aircraft will be required to handle an abundance of information from multiple sensors and automatically initiate action and/or present the crew with reliable decision aids that permit action to be initiated without assessing multiple independent information sources. This implies that an integrated avionics system will be required to process and transfer massive amounts of data from on-board and remote sensors at very high speeds as well as integrate navigation, communications, weapons, flight controls, and other functions to provide a high degree of system synergism.

Requirements

Based on estimates emerging from industry and government for future tactical aircraft, a quantitative information handling requirements model was developed and is provided in Figure 3. Referring to Figure 3, information handling is concerned with the flow and processing of data/information between the sensors and the displays and controls. Data rates between the pre-processors and signal processors are estimated to range from 200 to 500 mega-bits per second per channel and the data rates between the signal processors and data processors are collectively estimated to range between 100 and 200 mega-bits per second. These data rates are considered to be associated with the sensor distribution network portion of an avionic system. The data distribution network portion of the system (which connects the data processors to mission/aircraft subsystems, mass memories, and displays and controls) is estimated to range between 50 and 100 mega-bits per second. Total signal processing requirements are estimated at 10 x 10^9 operations per second while the capability of an advanced signal processor is projected to be on the order of 10^9 operations per second. Total data processing requirements are estimated at 50 x 10^6 operations per second while the capability of an advanced data processor is projected to be on the order of 2 to 5 x 10^6 operations per second. Other requirements include significant improvements in reliability as well as data fusion capability to optimize the use of all sensor information to enable the pilot to make rapid and accurate decisions.

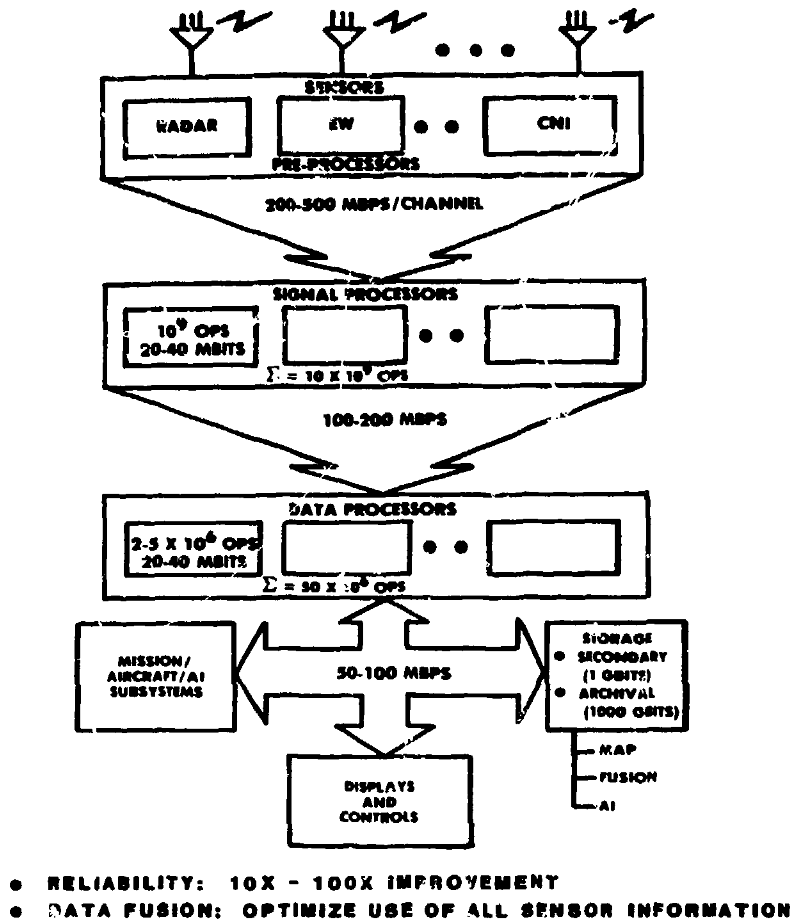

Figure 3. Advanced Information Handling Requirements Model

New Technologies and Concepts

Performance requirements indicate the need for signal and data processors using VHSIC technology speeds. In addition, the magnitude of processing required implies the need for multiple processors which will employ distributed processing and networking concepts. The high data rates required indicate the need for high speed fiber optic bussing as well as sensor and data distribution networking schemes. Achieving high reliability will require effective fault tolerance concepts coupled with high reliability VHSIC components.

Data fusion is a key that is required to optimize the use of available sensor information. However, fusion processing has difficult real time constraints both in the time in which to perform the required processing and required time response to rapidly developing situations. Performance could be increased by the use of artificial intelligence (AI) to provide additional tactical decision aiding functions. However, the incorporation of AI will require a vast, tailored knowledge decision tree operating in a real time environment. The use of data fusion and AI also implies the need for significant increases in memory storage capability, both on the primary and secondary levels.

Table 1 provides a summary of avionic system architecture goals and objectives and the means or technology needs for achieving these goals.

Table 1. Technology Needs

GOAL		MEANS
PERFORMANCE	• HIGH DATA RATES • HIGH PROCESSOR THROUGHPUT	• VHSIC PROCESSORS: 5-10X SPEED • FIBER OPTIC BUSSES: 50-100X BANDWIDTH • SENSOR FUSION/AI/INTEGRATION
	EASE TECHNOLOGY INSERTION	• DISTRIBUTED PROCESSING-INCREMENTAL EXPANSION • STANDARD BUSSES/INTERFACES • FLEXIBLE/STANDARD ARCHITECTURE INFRASTRUCTURE
FLEET READINESS	INCREASED RELIABILITY/ MAINTAINABILITY/ AVAILABILITY/ SURVIVABILITY	• FAULT TOLERANCE • VHSIC: BUILT-IN-TEST/REDUNDANCY • NETWORKING/RECONFIGURATION • FIBER OPTICS: EMI/EMP
LIFE CYCLE COSTS	MAXIMUM HARDWARE/ SOFTWARE COMMONALITY	• COMMON MODULE SET (40-50 MAX) • ADA SOFTWARE • ARCHITECTURE STANDARDS - NETWORKS/BUSSES/ INTERFACES
	DECREASED WEIGHT/VOLUME/ POWER	• VHSIC: 1/5-1/10 CURRENT TECHNOLOGY • INTEGRATED PACKAGING • RESOURCE SHARING
	FOSTER COMPETITION	• COMMON MODULE SET • ARCHITECTURE STANDARDS • INTEGRATED PACKAGING

Technical Issues

The choice of architecture will depend on the availability and maturity of key technologies and concepts as well as their ability to co-exist in a system environment. Issues regarding VHSIC and fiber optic technology include interoperability, insertion, and interfacing as well as their ability to support selected system topologies and concepts. Issues concerning distributed processing and networking include partitioning, communications, and control strategies. Issues concerning fault tolerance include techniques for fault detection, containment, isolation, and recovery. Issues concerning sensor fusion and AI include system integration requirements as well as additional information handling functions and resources.

Architectural Impacts

The evolution of avionics architectures, as a function of time, is depicted in Figure 4. Earlier systems employed single 1553 bus architectures which are growth limiting and subject to potential single points of failure. Newer systems as well as updated systems, employing current technology, are exhibiting the use of multiple 1553 busses as well as multiple processors. In general, the use of multiple busses and processors would tend to increase bandwidth as well as reconfiguration alternatives.

In the longer term, future systems will employ the advanced technologies and concepts previously discussed and shown in Figure 4. There are numerous approaches for incorporating these technologies and concepts into an avionics architecture. Possible implementations could range from multiple bus to total switch networks or some combination of these and other topologies. As shown in Figure 2, since the selection of an optimum architecture is subject to many factors and trade-offs, an architecture development model is provided in Figure 5 to facilitate analyses. This would enable the allocation of functional parameters, information flow, and the selection of appropriate coupling mechanisms.

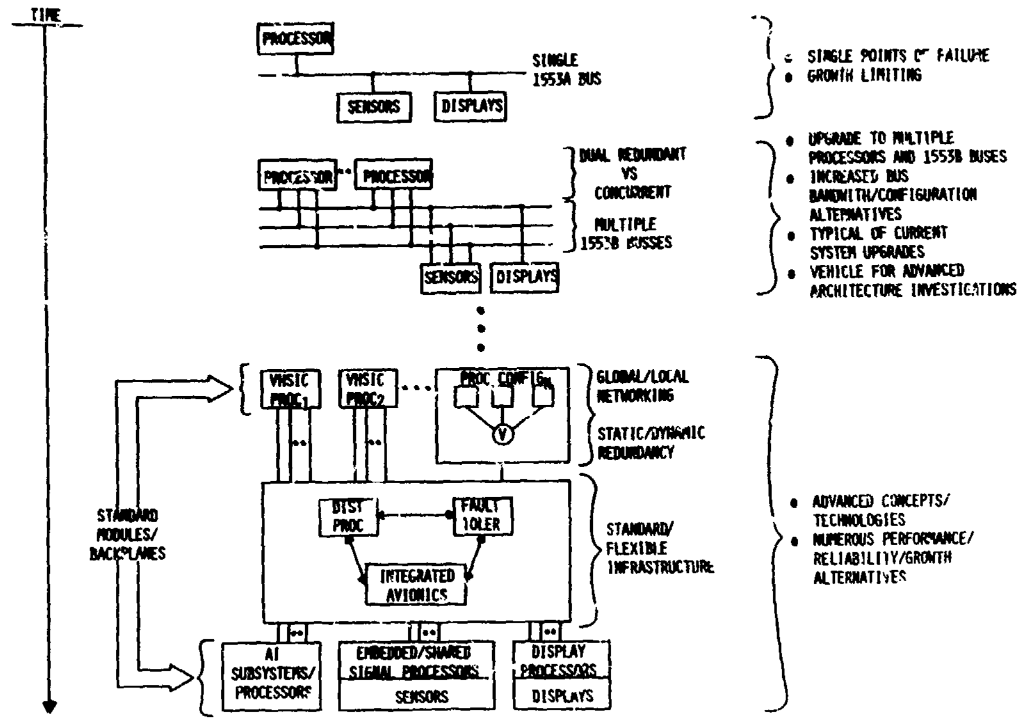

Figure 4. Avionics Architecture Evolution

To illustrate a possible implementation of an advanced architecture, consider the sensor distribution and data distribution network partitioning as shown in Figure 5. If the coupling mechanism connecting the signal processors were point-to-point fiber optic busses and a crossbar switch, then a resource sharing concept could be employed. By using a pool of signal processors rather than dedicating them to each sensor would enable the use of redundancy. This approach could provide a worst case signal processor to be spared for incorporating reconfiguration. Point-to-point bussing is required because of the high data rates (200-500 MBPS/channel) shown in Figure 3 while the crossbar switch would permit any sensor to be connected to any signal processor.

The sensor distribution network could connect to the data distribution network via a multi-drop, party-line, 50-100 MHz, dual redundant bus. Current concepts for incorporating a multi-port fiberoptic bus is by the use of star couplers. It is envisioned that multiple/distributed data processors, mission/aircraft subsystems, displays and controls, and possibly AI subsystems would communicate via this bussing configuration.

Further information regarding avionic computer architecture and alternative topologies is provided in Reference 2. Assessment factors that can be applied to qualitatively evaluating alternative architectures are provided in Reference 3.

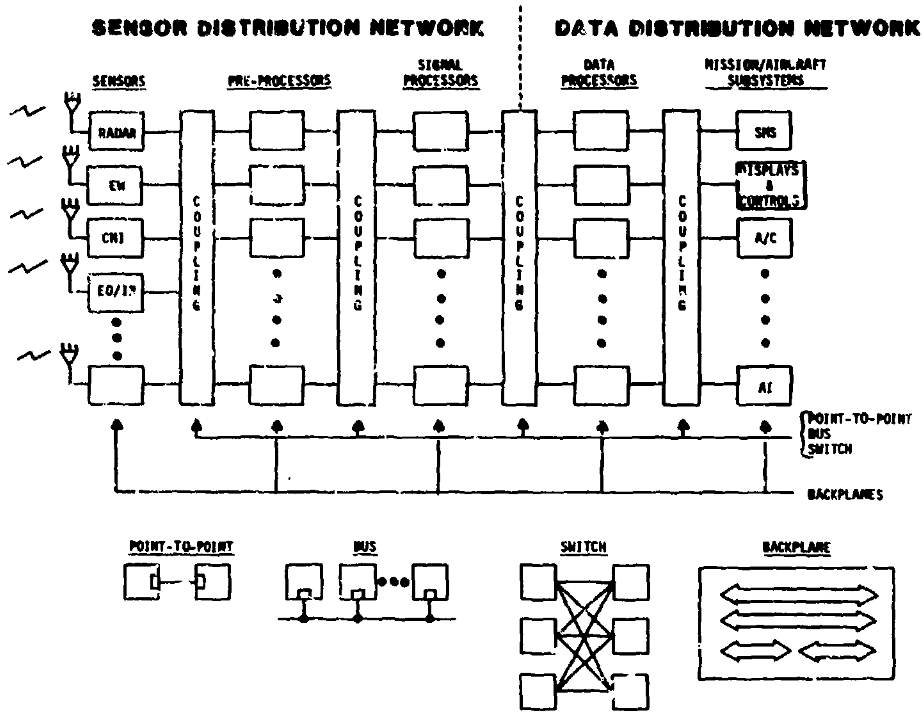

Figure 5. Architecture Development Model

CONCLUSIONS

Architecture implies structuring, organizing, and managing building blocks to achieve a required level of system performance. Avionics architecture building blocks include sensor, processing, display and control, and communication components. The design of an avionics architecture requires balancing and trading many factors.

Advanced avionics will require the use of new technologies and concepts. These include integration, sensor fusion, resource sharing, AI, VHSIC processors, fiber optic busses, distributed processing, networking, and fault tolerance. Issues to be addressed regarding these technologies and concepts include their availability, insertion, interfacing, and interoperability. Architecture impacts include sensor and data distribution network topologies as well as control schemes to manage and optimize resource sharing, distributed processing, and fault tolerance concepts. In addition, a standard/flexible infrastructure should be provided to enable ease of future technology insertion and optimize multi-platform/service applicability.

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THE DIGITAL COLOUR MAP
SIMPLIFIES GROUND ATTACK OPERATIONS

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SUMMARY

A pilot flying low and fast needs to know where he is all the time. He needs to know the nature of the local terrain and his actual track. He needs help in identifying waypoints, threats, and targets. He needs all this and more without distracting him from his attention to the safety of the aircraft and the overall demands of the mission.

The ideal way to provide this information is as a continuous colour map, orientated track up, with all associated information overlayed. It must also be usable by day and by night. No currently available equipment can achieve all these aims satisfactorily, other than a digital colour map generator providing video to a multifunction colour CRT display. Such an equipment has been developed by GEC Avionics and successfully flight tested.

Interest is now focussing on increasing the benefits that accrue from the use of the equipment in helicopter and fixed wing aircraft, in training, operationally, and as an aid to mission planning. The ease with which the digital map database can be updated and overlayed is a factor. It is as useful during mission planning as it is to the pilot in the air. This paper considers how such a computer aid might be used and identifies some of the increases in effectiveness that follow.

INTRODUCTION

Most modern aircraft designs configured principally for air-to-ground roles have recognised the importance of topographical information to the pilot by providing a projected map display in a prominent position in the cockpit. Examples are: Jaguar, A-7, Harrier, F-18 and IDS Tornado. All such systems to date have used electro-mechanical techniques to project an image of the map around the aircraft's present position from charts stored on optical film. The intention of providing the pilot with an automatic means of maintaining an awareness of his position and track in relation to the surrounding terrain and points of interest has only partially succeeded. Shortcomings, in no particular order of importance are:

(i) The dedicated map display occupies prime instrument panel real estate which cannot be shared with other sensors/functions;

(ii) It employs electro-mechanical technology which tends to be unreliable and requires maintenance skills which are becoming less and less available;

(iii) There is no provision for annotation of the map data with related mission information such as route plan, targets, threat data or other intelligence unless, as in some designs, radar or mission overlay symbols from a monochrome CRT are introduced via a beam splitter in the optical path. The complexity of such a technique in the confined space of a cockpit instrument panel can only aggravate the lack of reliability without adequately satisfying operational needs. Nevertheless, it is an approach which has benefited from great ingenuity. Today however other technologies are available which make alternative solutions much more attractive;

(iv) The use of optical film as the map storage medium leads to a considerable reduction in operational flexibility. Despite the provision of spools covering different operational areas, it is very difficult to ensure the availability of the right combination of scales of the required geographic areas. For example, it is not normally possible to predict in advance those target areas which might be required for future missions at large scale (1 in 50,000 or 1 in 100,000 and conveniently the same as those used by friendly ground troops). The spools generally contain smaller scales (1 in 500,000 or 1 in 1,000,000), with a large enough area to cater for as many potential missions as possible;

(v) The inflexible nature of the film storage medium leads to other problems. The long supply cycle ensures that information is out of date at issue and is unlikely to be updated at a greater frequancy than twice a year. To compensate for this pilots usually fly with additional papor maps, involving just the tasks considered to be unacceptable in the high speed low level environment and which the moving map is intended to avoid. The pilot has to carry paper maps for the larger scales with the greater detail and also the smaller scale paper maps with greater coverage marked up by hand with the latest chart amendments (CALF). These paper maps are used to fulfil primary functions. Only if they were carried as a last ditch alternative against the possibility of an equipment failure could they be justified;

(vi) Flying close to ground, particularly at night or in adverse weather, requires close to 100 per cent head up concentration. Head down glances should be restricted. Safety is bound to be affected if head down scans take more than a fraction of a second to complete. Examples of map generated delays and distractions are north/south transitions from one optical film strip to the next, manual selection of scale changes, or map slew/look ahead which can all take several seconds to complete. In his hostile high workload environment the pilot needs an instantaneous reaction to a command. Waiting for a response could be disastrous. (This consideration applies to other relatively slow access storage media too, e.g. optical disk, but not to random access semiconductor memory);

(vii) The requirements of night vision and compatibility with night vision goggles can not be totally satisfied by the introduction of optical filters or the control of display brightness. Greater flexibility in the control of individual map colours is necessary to reduce the general brightness of light coloured map background without losing the colour contrast necessary to pick out the information in the map. Significant light reflections around the cockpit at night are to be avoided;

(viii) Any techniques used to mix map and overlay information after subjecting each path to disimilar error sources is bound to degrade registration accuracy. Perfect registration can only be achieved by encoding both sets of information at source in a digital database;

(ix) An optical film allows no flexibility to provide desirable display facilities such as an electronic "zoom" or the ability to declutter unwanted information from the display;

(x) Optical film storage does not permit integration with the digital terrain databases likely to be required by other systems in the future. Two forms of database would need to be carried and be maintained. There would be no possibility of introducing some of the exciting new concepts into the map display, such as terrain avoidance or threat displays: it merely reproduces an image of the standard chart.

While I have listed a number of inadequacies in current projected map systems, there is no doubt that they have been well received by pilots. They have provided the essential direct link between the navigation systems computed present position co-ordinates and the pilot's appreciation of his relationship with the outside world. No longer should he need to identify his position and track on a paper map folded (or unfolded) in the confined space of his cockpit while simultaneously trying to avoid hazards and complete his mission. Automated map displays are potentially a major contributor to flight safety. One might have averted the mid air collision between a Harrier and a Starfighter in 1985, reference 1, and there are no doubt many more cases to support the argument. However, much more is now possible using current technologies. The ten criticisms of projected maps outlined above can all be overcome with the latest Digital Colour Map built by GEC Avionics. Indeed the map's value extends beyond the dedicated Ground Attack roles into those of Air Defence.

TECHNOLOGY OPTIONS

A general overview of the development of technologies from the earliest Projected Map Displays is given in Table 1. By the 1970s operators were aware of some of the shortcomings of these dedicated displays. They were unable to annotate charts by hand as they used to with paper maps and a need to provide radar updates of the navigation system by map matching was identified as a useful supplement to visual updates. At their best however, combined map and CRT displays designed to satisfy such requirements suffer from the majority of the problems already identified and in addition offer inferior resolution. A satisfactory solution had to await the 1980s and the development of:

- o high performance colour CRT displays
- o high capacity digital storage media

Table 1 Map Technology Progression

	1960s	1970s	1980s
Source Data	Film	Film	Digital Database
Image Generation	Electro-mechanically Driven	Electro-mechanical + monochrome CRT for Radar/Symbol Overlay	All Electronic
Image Presentation	Optical Projection	Optical Mixing & Projection	Multifunction Colour Display
Examples	Jaguar A-7 Harrier	Tornado F-18	AV-8B

The relatively recent but long anticipated demonstration of high brightness high resolution rugged shadowmask CRTs has met the need for truly multifunction cockpit colour displays. It is now entirely practicable to provide a relatively low complexity display, capable on the one hand of a high quality remotely generated colour map image and, on the other, of a FLIR picture with a resolution equivalent to that achievable on a monochrome display. The use of colour to highlight FLIR detected targets is a topic not yet fully explored. In the wings there remains the future possibility of even greater performance from the now emergent beam indexed CRT technology, slightly optimistically predicted for the early 1980s in reference 2.

The second technology development relates to the strides made in digital mass memories. Earlier magnetic media all suffered from physical size, environmental constraints or access time limitations. Only recently have optical disk and semiconductor memories been developed sufficiently to be considered practical options. Even today some doubts must remain with regard to the ability of an optical disk to meet full military environments bearing in mind the necessity of maintaining read head track and focus with a greater precision than the wave length of the laser light used. However, considerable effort is now being applied in these areas which should ultimately offer the potential of several hundred megabytes of memory in a relatively compact package. Other developments of the disk itself may permit the use of an erasable media instead of current "write once" technology. Even optical disk drives cannot fully meet map requirements for instantaneous access.

Long access times are not a problem which randomly addressed semiconductor memories suffer from. Requirements for large capacity memories of this sort have driven the technology to exceptional increases in bit densities. One megabit UV erasable EPROM chips are available today with 4 megabit devices promised in the future.

The development of efficient data compression algorithms has given greater map area coverages using more restricted memory capacities. Actual compression ratios achieved vary with the map content but sufficient work has now been done to confidently predict achievable values. This has led to relatively economic map memory designs using EPROM technology with no attendant doubts about environmental soundness.

An intermediate technology not discussed so far uses the older optical film storage technique and converts the image to an analogue video signal for remote display on a colour CRT. While obviously benefiting from the use of a multifunction cockpit display and preserving the use of existing film database support systems, this hybrid approach founders by preserving most of the inadequacies of the current projected map systems listed above. It is unlikely to find a role in the face of competition from digital map generating systems in the future, nor can it benefit from the existing and emerging digital databases.

THE DIGITAL COLOUR MAP

The GEC Avionics Digital Colour Map has been described before, reference 3. This discussion will therefore be limited to an outline description, identifying key features of the latest design configuration.

Earlier versions have been flying in a Royal Aircraft Establishment Wessex helicopter since October 1984 and have since been delivered to support a US simulator programme. Equipments of this class will also be delivered for an RAE Lynx helicopter programme and the British Army Phoenix UMA where it will be a key feature of the Ground Station. Fixed wing flight trials are expected to begin soon in the RAE Hunter and a US Navy A-6. In all cases the digital database has been prepared in-house using, in some cases, subcontract map digitisation. An enthusiastic response from the pilot community has been received.

Figure 1 shows a simplified block diagram of the Digital Colour Map. A key feature is the partitioning of the database memory into two categories: that which changes infrequently but is required in very large quantities; and that which is changed from mission to mission but of which there is conveniently less:

(i) EPROM data, consisting of large areas at several scales of compressed map data formatted as small individual "tiles". This data would normally be changed only in the event of out of area operation or when the map is subject to its relatively infrequent but regular update requirements. The tiles can either be composite or be subdivided into feature plane layers to facilitate the declutter function and to allow DLMS DTED (Digital Land Mass Survey, Digital Terrain Elevation Data) to be introduced in place of contours/elevation shading.

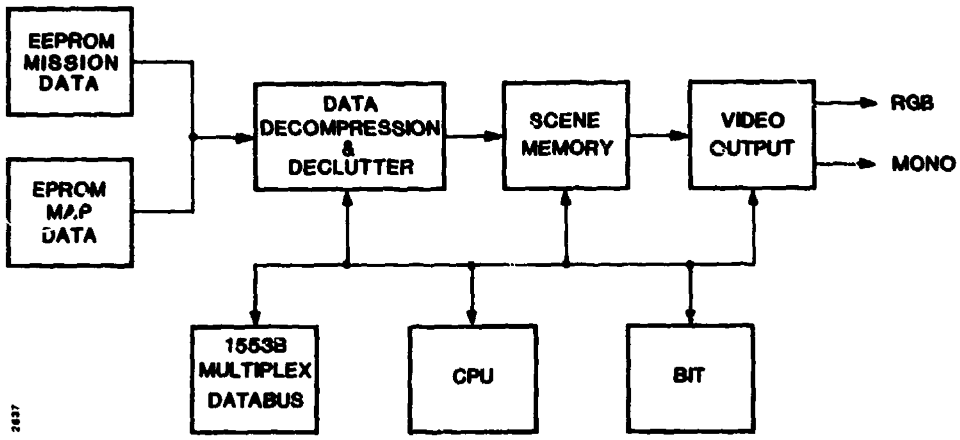

Fig. 1 Digital Colour Map

The DTED gives the flexibility to reproduce contour lines or provide alternative displays for terrain avoidance, threat avoidance, radar shadowing, etc. Although EPROMS require UV exposure for erasure, they currently provide the most economic form of non-volatile semiconductor memory.

(ii) EEPROM data, consisting of mission specific data. It is normally inserted as a cartridge but can be loaded in situ from an external port and a ground support bus. The data is generally formatted in the same way as the EPROM map data and is indexed to provide exact correspondence. Typical data are the limited area large scale maps which can only be identified at target briefing prior to the mission, targets, waypoints, routes, known threats, FEBA, FLOT, or the aeronautical overlays which change so frequently in peace time. Although more convenient to use than EPROM, EEPROM at this time provides about a quarter of the density at four time the price per bit. It would not currently be econcmic to use this media for the whole memory.

The microprocessor based CPU is controlled by software resident in non-volatile memory in the CPU card. It controls the data flow from the databases according to commands received over the multiplexed data bus. It calculates the map areas required to update the scene memory and initiates transfer of this data plus any overlay to the Decompression card. The data is then reformatted into the expanded pixelised form required by the scene memory. Part of this reformatting involves selection/deselection of overlay/map layers according to the level of declutter selected by the operator. The area maintained within the scene memory is in a North-up format, and from this the area to be displayed is accessed with the appropriate orientation and present position. The size and rate of update of this store is sufficient to allow smooth rotation and scrolling of the display with no discernible breaks in the map picture.

The colour palettes on the Video Output card further condition the data by assigning colours to the pixel codes. Several palettes can be stored and selected by commands on the Multiplex Data Bus.

While the block diagram outlines the functions necessary to produce an image of a conventional map, some additional facilities are required to make full use of the DTED data, or to interface the database with other user systems. The ability to interface a large capacity optical disk drive system in place of the EPROM memory is a feature of the design.

Typical map images are shown in Figures 2 and 3, but of course in monochrome in this reproduction.

Operational modes are:

- Switch-on/Standby
- Normal
- Slew
- Test

During Standby, initialising operations including self test are carried out automatically. The processor then interrogates the database and indicates the geographic coverage and scale on the cockpit display.

During Normal, the map automatically aligns to present position which is centred in the display screen in the North-up mode or offset in Track/Heading-up modes to provide increased "look-ahead". Typical functions include:

- Map orientation - North, Track or Heading-up
- Scale selection
- Zoom - continuous to 2:1
- Mission overlay
- Declutter
- Look-ahead - to selected waypoint/target
- Mark or Regress - to identify points of interest
- Colour Palette Selection - day/night

In the Slew mode, the map may be offset under manual control to provide a visual fix update of the navigation system. This feature may also be used to review map areas away from present position as an alternative to the Look-ahead function.

In the Test mode, normal operation is interrupted and an easily interpreted test pattern is presented to the operator.

The Digital Map is typically 3/4 ATR short size and dissipates 150 watts.

DIGITAL DATABASE

Although there are several databases available internationally, coverage is incomplete. There are plans in both the US and UK to establish standard digital databases for cultural information, becoming available from the early 1990s. In the interim electronic maps must make use of existing material.

GEC Avionics have experience of using several different sources. They include:

- Digitisation of paper charts
- Digitisation of individual ink/feature planes which are used by the printers as source material
- Use of UK PACE vector data
- Use of DLMS DTED

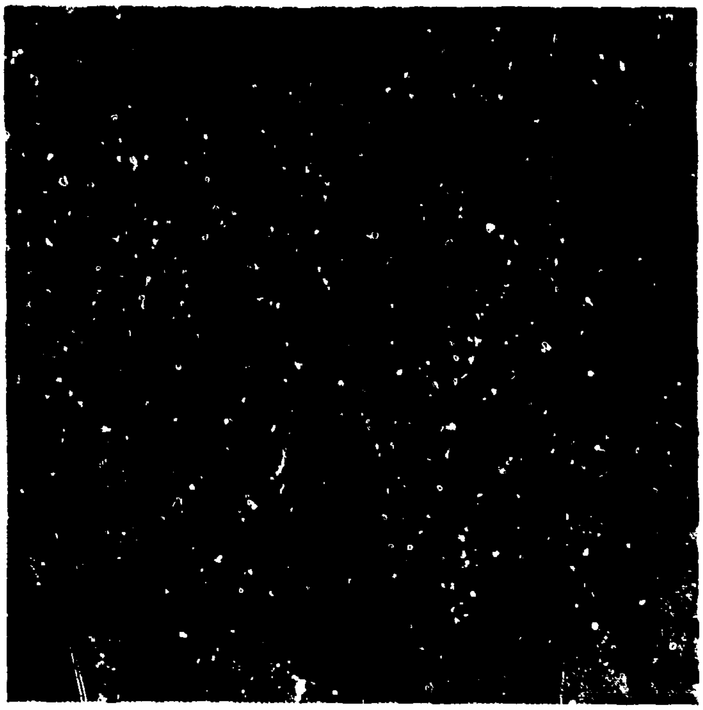

Fig. 2 Digitised Map (50,000:1 Scale) Displayed at Zoom Factor 1.0

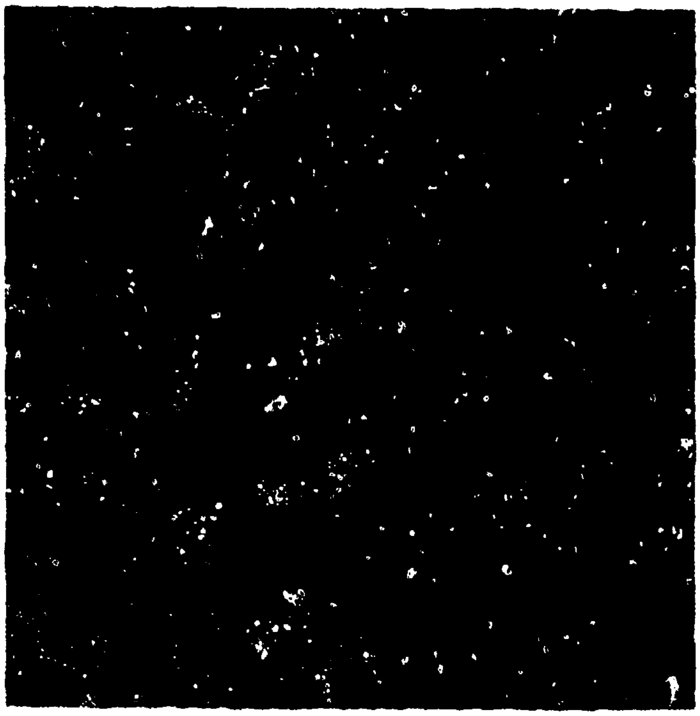

Fig.3 Part of the Same Area Displayed at Zoom Factor 2.0

The blending together of these sources has been demonstrated successfully. Figure 4 outlines a general scheme reflecting the tasks to produce map data in an efficient form for loading into the aircraft. National mapping agencies would normally provide the top tier of source data to an agreed standard. A central facility would most probably also be involved in producing compressed tile data in a format suitable for downloading to the aircraft. The only facility essential to the local base is a memory system to hold the above extensive compressed data and the ability to select a subset for particular aircraft and download this into EPROM or EEPROM. This facility might most usefully be linked to a multiple Mission Planning facility, networked to a similar work station for the intelligence officer's use.

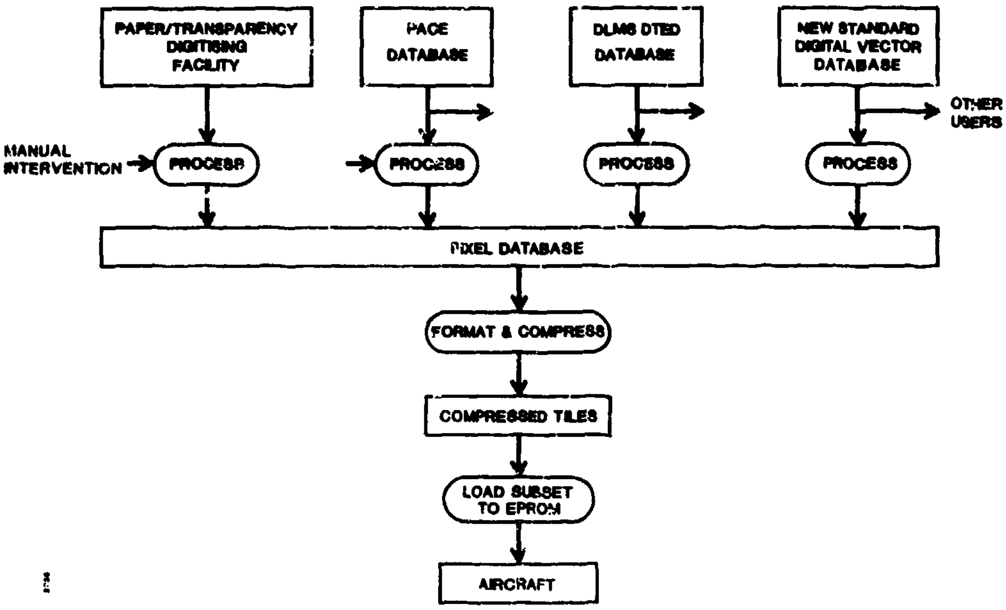

Fig. 4 Comprehensive Map Digitisation Scheme

MISSION PLANNING

A key feature of the map is its use during mission planning, allowing complete missions to be developed and "flown through" on the ground using the same information that is available in the air. Targets or waypoints can be identified and verified on the map before loading into the system, as can relevant intelligence data. The mission planning process can take over a multitude of processing tasks currently carried out manually or in a fragmented manner. Fig. 5 shows such a simple user friendly facility. Other capabilities could be straightforwardly added, such as a printer for a permanent record, a video frame snatching facility to allow IR reconnaissance pictures to be viewed, selected and loaded into the mission database if required.

The Mission Planning Station can also be used for debriefing. On reloading the EEPROM cartridge, information recorded in flight can be re-run, including possibly mark/regress points, new threats identified during a mission, and many other features. It would also be straightforward to record the actual route flown and compare this with the intended one. Actual time over the target could be compared with that planned. Although potentially valuable for training purposes, such a facility is likely to be as popular with pilots as the tacograph is with truck drivers.

A very important capability of the Mission Planner is the provision of absolutely up-to-date CALF data as an overlay on the electronic map. It also enables the required large scale map patches to be carried as an aid to IP and target identification. Both of these facilities should ensure the pilot does not need to use any paper maps under normal conditions. He would only carry them for use in the event of an equipment failure when he could expect some reduction in operational capability.

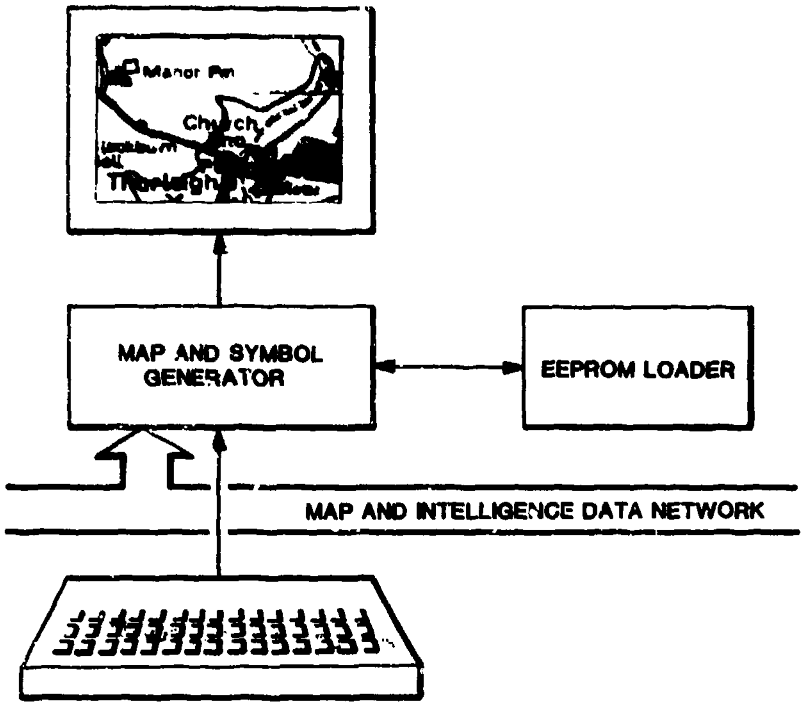

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Fig. 5 Mission Planning Station

CONCLUSION

Digital Colour Map technology is with us today. Technical risks have been eliminated. The Mapping Agencies are now advancing their plans for cultural database systems of the future. Very significant benefits to the low flying helicopter and fast jet pilot are in the offing. Some of these benefits will also aid the air defence pilot where knowledge of terrain and situation awareness is also a factor. Integration of the map with other terrain referenced functions is planned, sharing the database overhead. Some of these future development are discussed in a paper by Mr L Busbridge later in the symposium.

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CONSOLIDATED LAND ATTACK MISSION PLANNING STATION (CLAMPS)

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ABSTRACT

The proposed mission planning station described in this paper is a result of a Naval Weapons Center discretionary funded study performed in conjunction with the AV-8B Program Office in 1985. The approach described draws heavily on the development and deployment of digital map technology for use on modern attack aircraft. The characteristics of the digital map are derived from a draft product specification currently being prepared for submission to the Defense Mapping Agency (DMA), and the AV-8B requirements document for a digital map capability. The envisioned digital map would utilize optical disk storage for the map, and additional solid state storage for the annotation generated by the planning station. The mission planning station is shown in three configurations ranging from a baseline capability (which may even be appropriate for an individual aircraft), up to a fully capable station capable of interacting with other digital data bases and even generating its own optical disk.

BACKGROUND

The critical difference in this proposed mission planning station approach is the digital map capability envisioned for future aircraft. In order to put the impact of the digital map capability into better perspective, a brief discussion of this technology is warranted. For all versions of digital map a navigation computer interfaced to an inertial navigation unit (INU) is assumed. No specific implementation will be described, but instead a generic digital map will be described. For a more complete discussion of this topic, see reference (1).

Navigation for pilots has been in a state of slow evolution ever since the Wright Brothers could fly far enough to get lost. Early navigation was accomplished by pilot recognition of landmarks, and has evolved to the flight maps used by pilots throughout the world. But navigating with maps was rapidly found to be deficient during bad weather, at night, and when the pilot was in sufficiently unfamiliar terrain. Military applications demanded solutions to these deficiencies. Radio beacons (e.g., TACAN) were one way to stretch invisible lines through space to augment navigation. But the vulnerability of these links has been recognized and autonomous navigation techniques were soon sought. The INU, a complex set of gyros and accelerometers was developed to provide positional information. Since these systems have inherent (and typically random) drifts, they require initialization, alignment, and updates to maintain the needed accuracy. It was recognized from the navigation designate (update) mode that a correlation could be made between inertial space and a map space. So the projected map display was born. A film strip of DMA maps is produced to cover the expected operating zone for an aircraft. The initialization of the INU and the film strip are performed simultaneously, and a pilot can watch his position superimposed on a photographically produced map (see Figure 1) from A-7 aircraft. This leaves the pilot's hands free to operate his controls with no further need to juggle flight charts. For missions requiring precise weapon delivery time and location, this system is a fantastic improvement. So why do we need digital maps? Especially since current cathode ray tube (CRT) displays will never match the resolution of a photographic image.

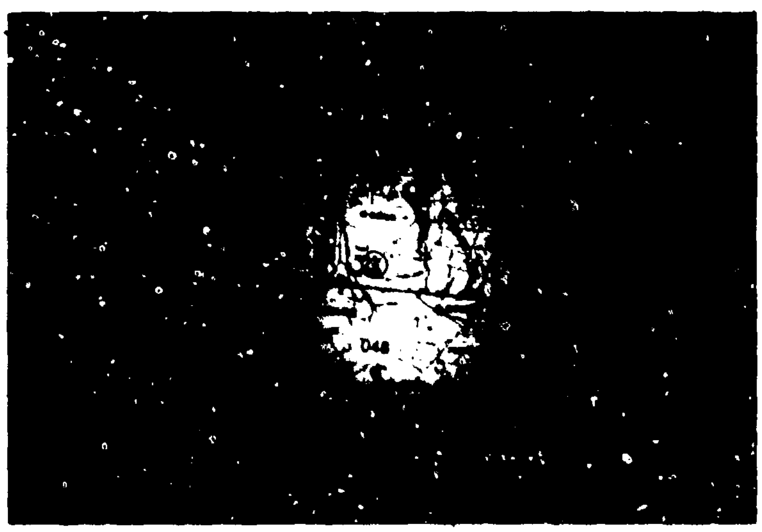

FIGURE 1. A-7 Projection Map Display.

The current photographically based projected map displays are limited to standard paper map formats. An area of complication can occur due to the diversity of map formats. The ground forces typically utilize a map called Universal Transverse Mercator (UTM), while aircraft navigate in latitude and longitude. So the maps are not the same, and the confusion is difficult to resolve. Conversions can be made between positions on both types of maps, but cannot be readily displayed on photographic projections of maps. So what is needed is an absolute map standard which can be readily converted into any format. The Defense Mapping Agency (DMA) is involved in the development of this data base. Using a variety of information sources, a digital representation of the surface of the earth can be generated (Figure 2). The Digital Land Mass System (DLMS) is currently available in two general classes:

Digital Terrain Elevation Data (DTED)

Digital Feature Analysis Data (DFAD)

FIGURE 2.

Each class is composed of many subgroups depending on the level of complexity. The accuracy goal for these data sets is considerably better than that available from paper maps. So digital map technology ultimately will involve a match of highly accurate digitized position information to low drift inertial systems. Intermediate steps may involve digitization of paper maps (Figure 3) due to issues of availability and uniformity. Of course, once the position information is in a digitized format it can be manipulated and this is where the real pay-off occurs.

In particular, this digitized map information can now be integrated with reconnaissance, and intelligence information to provide a greatly improved land attack mission planning capability. A potential method for accomplishing this integration is described in this paper.

FIGURE 3.

OBJECTIVE

CLAMPS is an approach to developing a modular ground support station for aircraft equipped with digital moving map displays. An attempt is made to match the capabilities of each level of modular station to the envisioned requirements for that level.

The mission planning station is initially configured for the AV-8B aircraft with growth to the F/A-18 and V-22 (i.e., JVX).

AV-8B REQUIREMENTS

The Night Attack version of the AV-8B requires the following digital map capability:

Coverage - minimum 400 nm x 400 nm

Scale - 250,000 to 1 } selectable
- 50,000 to 1

Display - Multi-purpose Color Display (MPCD)

INU Drift - 1 nautical mile/hr.

The current development contract for this hardware was awarded to Sperry, and is scheduled for delivery and installation in May 1987. Although Sperry initially proposed only 300 x 300 nm (about 60 sq. ft. of paper map), they have been instructed to consider broader coverage (up to 100 sq. ft. of map). This system will initially be based on digitization of paper maps. Even though Sperry has

selected an extremely dense storage media (the optical disk (Figure 4)), they will still require some data compression. There are a number of methods to accomplish this compression, all with some inherent level of information degradation.

OPTICAL DISKS PERMANENTLY HOLD INFORMATION PROTECTED INSIDE THE SURFACE LAYERS

WRITING CAUSES A NON-REVERSIBLE PHYSICAL CHANGE TO THE MEDIA

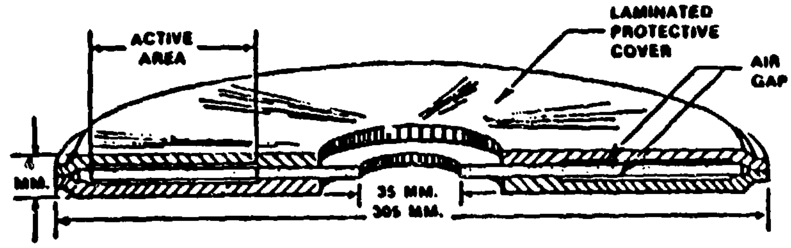

ILLUSTRATION OF 12" MEDIA, COURTESY OF 3M.

FIGURE 4.

GROUND RULES FOR CLAMPS

The mission planning station described here is a prototype for all attack aircraft utilizing a digital map. The station can exist in varying levels of sophistication depending on the functions required and the hardware/software limitations available. It is assumed it performs the same function as the Computer Aided Mission Planning Station (CAMPS) which has been prototyped for the U.S. Marine Corps. Its capabilities will be divided into three groups, all having a baseline capability which is then expanded as needed. The system must be capable of using a variety of digital inputs such as:

1. Paper Maps (after appropriate digitization)

2. DMA Data (DLMS)
   DTED
   DFAD

3. Tactical Electronic Reconnaissance Processing Evaluation System (TERPES) (Reconnaissance Data)

4. All Sources Image Processor (ASIP) (Intelligence information)

5. LANDSAT

The details of some of these data bases are classified and will not be described here. Suffice it to say that CLAMPS will require special software to utilize these data bases.

The output of CLAMPS will be optical disks and other solid state memory sources, which can be introduced into the aircraft.

DATA BASE DISCUSSIONS

Paper maps are the most readily available and offer the broadest coverage. They are from basically three sources.

1. Defense Mapping Agency

2. U.S. Geodetic Survey (USGS)

3. Native Editions (derived from international sources)

The current draft product specification will specify the format for DMA to digitize paper maps (all sources) and record them onto optical discs. The amount and type of compression required is yet to be determined. In time the source will switch from paper maps to the Digital Land Mass System (DLMS) products mentioned earlier (DTED/DFAD). The familiarity of DMA with all of these products makes them the ideal choice for accomplishing this task. DMA currently produces the photographic maps for the projected map displays (e.g., A-7).

TRAPES, ASIP and LANDSAT to a certain extent, require special processing and only limited access is available or expected.

COMPUTER-AIDED MISSION PLANNING STATION (CAMPS) FUNCTIONS

The CAMPS functions are considered critical to any advanced Land Attack Mission Planning Station. In particular, CAMPS currently uses DMA elevation files (DTED) to generate a terrain data base. It then includes aircraft flight parameters and threat locations and envelopes to generate an optimum flight profile (position and altitude). A prototype of CAMPS was operated in the Fleet on the U.S.S. Saratoga. A block diagram of the hardware is shown in Figure 5 and the equipment layout in Figure 6. It is intended that CLAMPS can incorporate these functions in equipment requiring comparable, if not less, size, weight and complexity. The basic information flow is shown in Figure 7, which in general is an iterative process requiring considerable operator involvement.

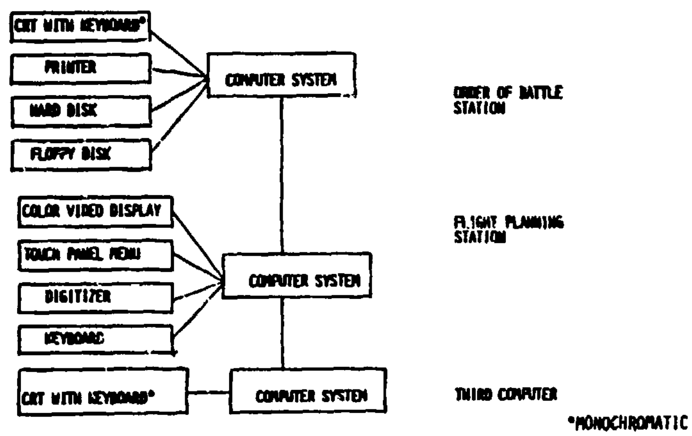

FIGURE 5.

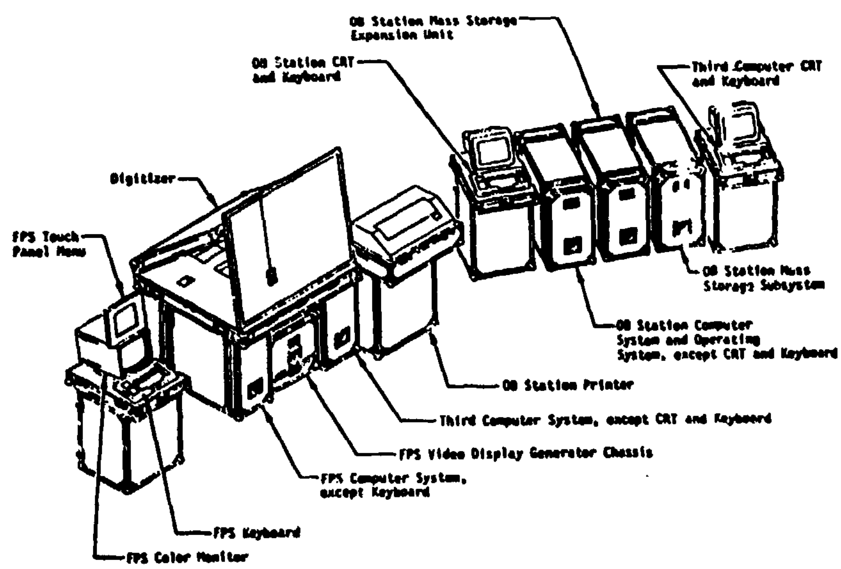

FIGURE 6.

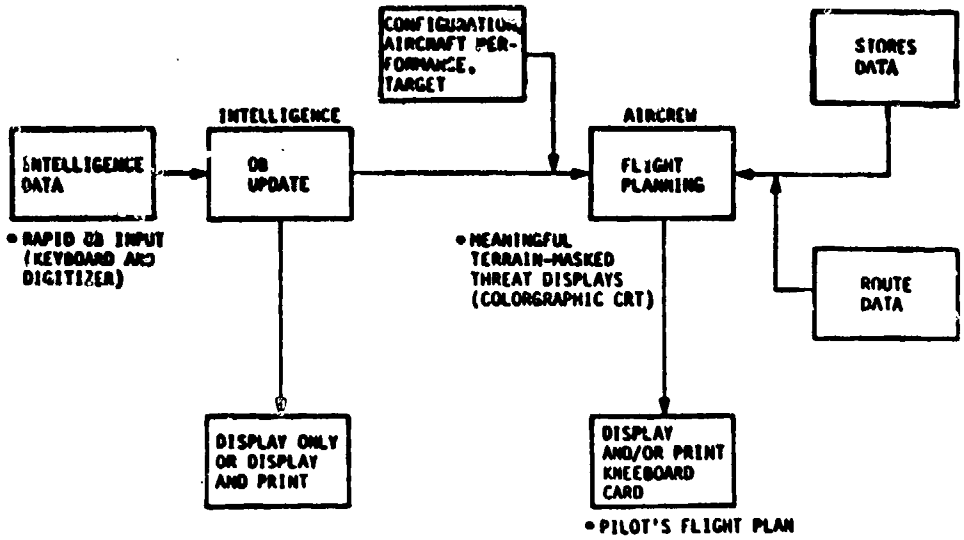

FIGURE 7.

STORAGE MEDIA CONSIDERATIONS

As indicated earlier, the optical disk is the media selected to store the map information. Currently, a 5 1/4 inch compact optical disk (size of current compact disks) could readily store 260 megabytes (per side) of information. It is likely that this could be increased and schemes have been identified to write on both sides of an optical disk. Currently, the aircraft installation would involve a single optical disk drive with one or two readout heads. It would store basic map information in some compressed format. The fastest schemes for writing optical disks of the needed density and coverage would require one half hour to prepare. So it is envisioned that an optical disk library of the world would be created to support mission planning. As mentioned earlier, this would initially involve digitization of paper maps with their attendant shortcomings (inaccuracies, lack of feature information, etc.), and ultimately be expanded to the DLMS data sets. For operational use, a scheme to rapidly introduce annotation onto this data base would involve another storage media. One option for this is a memory card Data Storage Unit (DSU) under development for the F/A-18. The characteristics of this storage unit are summarized in Table 1. It can be rapidly written, erased, and updated but has only a very limited data storage capability. This makes it a good match to the denser storage, but less flexible optical disk media.

TABLE 1. Digital Storage Unit (DSU).

Current Function	Initialize JTIDS; store flight incidence information
Size	80 cubic inches
Weight	4 lbs
Storage Capability	4 MBIT expandable to 32 MBIT
Power Consumption	< 10 watts

MISSION PLANNING STATION ARCHITECTURE

As mentioned earlier, the system is intended to be modular allowing a variety of configurations based on required capability. For simplicity only three configurations will be described here; a minimum required capability system, a squadron level planning system, and a full blown conus or carrier-based planning system.

Level I

Level I is shown in Figure 8. It involves a capability to read an optical disk (OD) and the contents of the DSU. Since these two storage media cannot interact directly, a data synthesizer is needed to call up annotation at the appropriate portion of the map. This could be included in the central processor, but since it is needed in even the aircraft installation, would probably be a stand-alone microprocessor. The operator would need a means of interacting with the DSU to generate and update annotation information. The operator input options would involve a terminal, hand controller, or potentially a touch panel overlay. The touch panel would be superimposed on the display to allow rapid annotation. The central processor would be needed to extract the stored information from both sources and produce the digitized map display. Once the information has been generated or updated, the processor must be capable of writing the DSU and potentially even produce a multi-color paper map (including annotation) for non-digital map equipped aircraft (or even as a back-up for digital map systems). The processor has not been identified but a desk top unit (personal computer) is a potential candidate system.

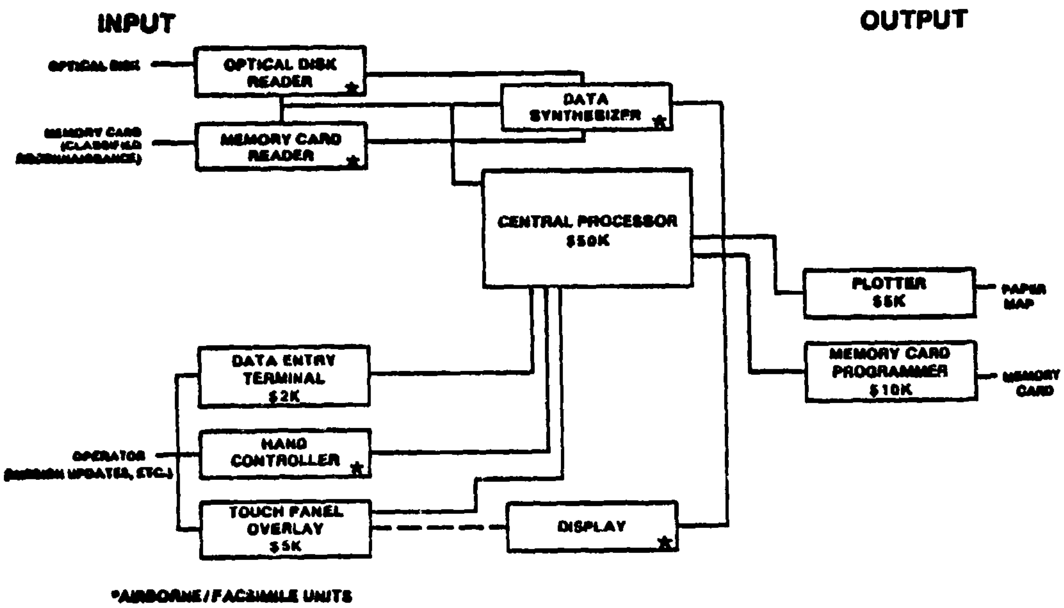

FIGURE 8.

Mission planning time frames may drive the processing requirement to larger, more expensive machines with higher throughput. The prices indicated are based on off-the-shelf hardware.

Level II

Level II (Figure 9) has all of the Level I modules, as well as the following additional items:

Magnetic Tape Drive

Map/Photo Digitizer

Micro-VAX (ruggedized)

With the additional features it could interact with other digital data bases; TEEPES (reconnaissance), ASIP (intelligence), LANDSAT (feature source). Proper preparation and interfaces of these data bases could support high speed insertion of threat, target, friendly force location to aid in mission planning. This level would still not be capable of interacting directly with the optical disk storage media.

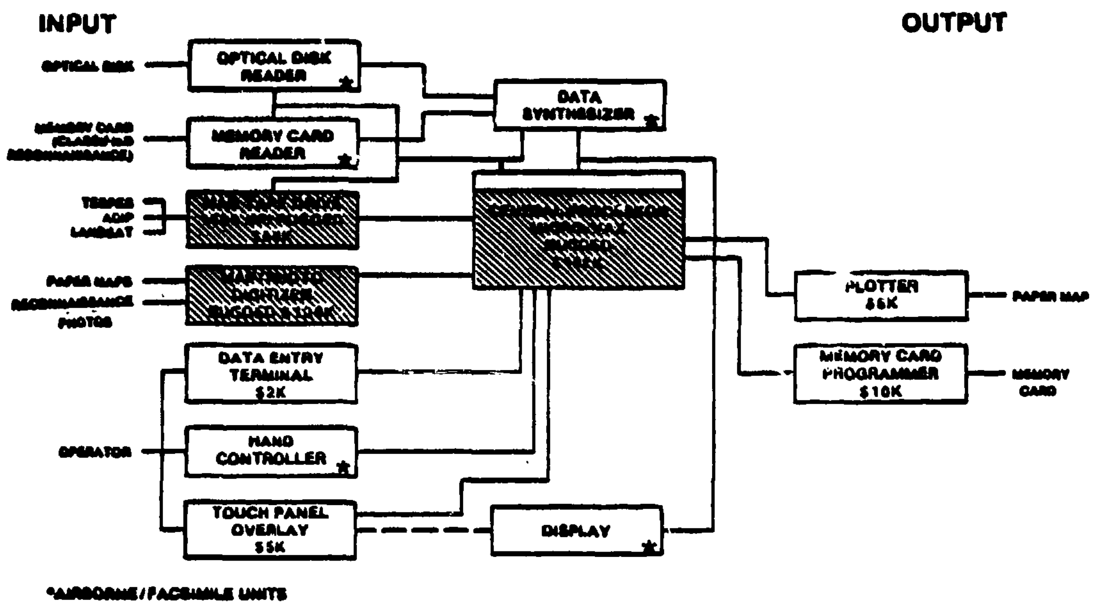

FIGURE 9.

Level III

The configuration shown for Level III (Figure 10) is the fully capable system intended for carrier (LHX) or CONUS sites. It involves the addition of two more key modules:

1. Ruggedized VAX-750 or equivalent

2. Optical Disk Writer

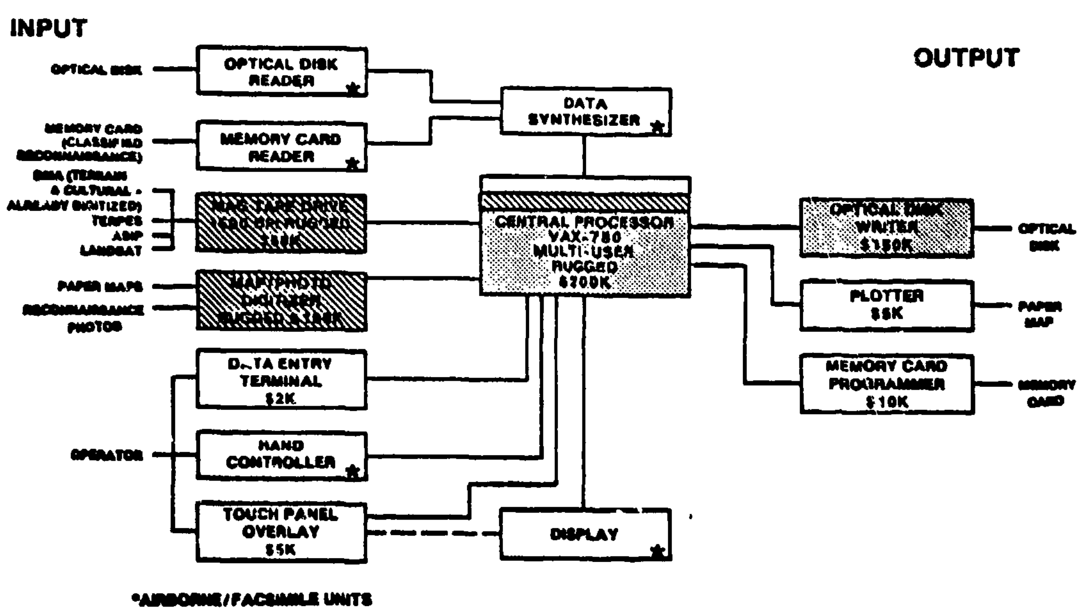

FIGURE 10.

This system could interact with the optical Disk Library directly. In fact, it could draw on the library to extract only the sections needed for a mission area and optimize their storage for rapid display and annotation. It would also allow incorporation of limited feature information to the optical disk to improve user utility. The system could then generate copies of the disks to be distributed to the squadrons for their utilization. Costs shown again are the off-the-shelf commercial hardware, which may not be applicable for military use.

FUNCTIONAL MATRIX

All of the functions considered critical for CLAMPS are listed in Table 2, along with the hardware modules required. It can be readily shown that some hardware subsets are always required for use together. So these are combined into modules. The list of modules is as follows:

Read/Display Module

Optical Disk Writer

Memory Card Writer

Annotate Module

Mag Tape Drive

Digitizer

CPU

Processor

A potential user could, by identifying the functions he needs to perform rapidly, determine the set of modules needed to support this. So mission planning stations could be readily tailored to the user needs.

SUMMARY

CLAMPS is a proposed mission planning capability based on a generic digital map technology. It is intended to support a number of attack aircraft and user requirements. It performs all of the existing CAMPS functions and adds additional features. Although optical disk and solid state memory are projected for this capability, it could be used for other data storage media. An evolving system based initially on digitized maps is described, as well as growth potential to higher accuracy DLMS data bases. The functions are tailorable depending on the modules selected. This is intended as a candidate architecture currently for planning purposes only.

REFERENCE

1. Shupe, Norman K., U.S. Army Avionics Research and Development Activity, Fort Monmouth, NJ, presented at the 37th Annual Forum of the American Helicopter Society, New Orleans, LA, "The Night Navigation and Pilotage System," May 1981, Reference number 81-18.

TABLE 2. CONSOLIDATED LAND ATTACK MISSION PLANNING STATION (CLAMPS).

	Read/Display Module							Annotate Module						
	Optical Disk Reader	Memory Card Holder	Data Synthe-sizer	Display	Optical Disk Writer	Memory Card Writer	Plotter	Data Terminal	Hand Controller	Touch Panel Display	Mag Tape Drive	Digitizer	CPU (incl. terminals	Mission Planning Processing
PREPARE AIRCRAFT INPUTS														
Generate Optical Disks	X	X	X	X	X						X	X	X	X
Generate Memory Cards	X	X	X	X		X		X	X	X			X	X
Plot Color Strip Maps	X	X	X	X			X						X	X
GROUND ANNOTATION														
Display 3-D Color Map	X	X	X	X									X	X
Enter Symbols from Ground Sta	X	X	X	X		X							X	X
Enter Coo-dinates in Lat/Long	X	X	X	X		X							X	X
Enter Coordinates in UTM	X	X	X	X		X							X	X
Enter Coordinates by Pointing	X	X	X	X		X				X			X	X
Change Scale	X	X	X	X									X	X
Add/Delete Terrain Features	X	X	X	X		X		X	X	X			X	X
Display Performance Parameters by Day Type (Weather)	X	X	X	X									X	X
COCKPIT ANNOTATION														
Display 3-D Color Map	X	X	X	X									X	X
Enter Symbols from Cockpit	X	X	X	X		X		X	X	X			X	X
Update Present Position from Cockpit	X	X	X	X				X	X	X			X	X

TABLE 2. CONSOLIDATED LAND ATTACK MISSION PLANNING STATION (CLAMPS) (Contd.)

	Read/Display Module				Optical Disk Writer	Memory Card Writer	Plotter	Annotate Module			Mag Tape Drive	Digitizer	CPU (incl. terminals	Mission Planning Processing
	Optical Disk Reader	Memory Card Holder	Data Synthesizer	Display				Data Terminal	Hand Controller	Touch Panel Display				
Change Scales	X	X	X	X				X	X	X			X	X
Add/Delete Terrain Features	X	X	X	X				X	X	X			X	X
DISPLAY MODES														
Digitize Paper Maps and Recon Photos	X	X	X	X								X	X	X
Copy and Display 2-D Color Map	X	X	X	X			X						X	X
Display Overwrite Data W/O a Map Background	X	X	X	X									X	X
Orient Map to North Up or Tracking Up	X	X	X	X									X	X
Position A/C Symbol at Bottom or Middle of Screen	X	X	X	X									X	X
Process ELINT Data	X	X	X	X			X					X	X	X
Process Satellite Data	X	X	X	X			X					X	X	X
INITIALIZE FUNCTIONS														
Inertial Systems	X	X	X	X									X	X
JTIDS	X	X	X	X									X	X
Communications	X	X	X	X									X	X
Weapons	X	X	X	X									X	X
EW Suite	X	X	X	X									X	X

TABLE 2. CONSOLIDATED LAND ATTACK MISSION PLANNING STATION (CLAMPS) (Contd.)

	Read/Display Module							Annotate Module						
	Optical Disk Reader	Memory Card Holder	Data Synthesizer	Display	Optical Disk Writer	Memory Card Writer	Plotter	Data Terminal	Hand Controller	Touch Panel Display	Mag Tape Drive	Digitizer	CPU (incl. terminals	Mission Planning Processing
SURVIVABILITY INFO														
Intervisibility Plots	X	X	X	X			X						X	X
EW	X	X	X	X			X						X	X
TERFES	X	X	X	X			X				X		X	X
ASIP	X	X	X	X			X				X		X	X
STRIKE INTEGRATION														
Coordinate with EA-6B Support	X	X	X	X									X	X
Attack Info for Other Strike Aircraft	X	X	X	X									X	X
Time on Target	X	X	X	X									X	X
Weapon Selection	X	X	X	X									X	X
ECM Options	X	X	X	X									X	X
MISSION PLANNING (CAMPS)														
Generate Flight Paths	X	X	X	X			X						X	X
Select Aircraft													X	X
Choose Between Coverage and Danger Modes													X	X
Incorporate Terrain Masking	X	X	X	X									X	X
Control Types of Features Displayed	X	X	X	X									X	X

TABLE 2. CONSOLIDATED LAND ATTACK MISSION PLANNING STATION (CLAMPS) (Contd.)

	Read/Display Module							Annotate Module						
	Optical Disk Reader	Memory Card Holder	Data Synthesizer	Display	Optical Disk Writer	Memory Card Writer	Plotter	Data Terminal	Hand Controller	Touch Panel Display	Mag Tape Drive	Digitizer	CPU (incl. terminals	Mission Planning Processing
Define Aircrafts' Configuration Load													X	X
Designate Targets for Strike Mission	X	X	X	X									X	X
Revise Routes & Generate Alternate Flight Paths	X	X	X	X			X						X	X
Save and Recall Routes													X	X
Clear Mission and Start Over													X	X
Position Digitizer Along Either Axis												X	X	X
Define JP for Each Target	X	X	X	X									X	X
Define Time on Target	X	X	X	X									X	X
Designate Point Where External Fuel Tanks are Jettisoned	X	X	X	X									X	X
Invoke Weapon Release Calculations	X	X	X	X									X	X
Invoke Pop-up Parameter Calculations	X	X	X	X									X	X

DISCUSSION

H.A.T. Timmers, Netherlands

Which firms are delivering ruggedized optical discs?

Author's Reply

Ruggedized optical disks are not now being delivered. U.S.A.F. RADC has a program to develop such a disc. It is called The Tactical Optical Disc System. The program manager is Albert Jamberdino. McDonnell Douglas at St. Louis has contracted Sperry to build such a system for the AV-8B. Other companies are working to develop ruggedized optical disks also.

J. Whalley, UK

Are you able to say anything about the software or algorithms that are used in this system?

Author's Reply

No. This study indicated what components would have to be put together to obtain desired function in a digital-map support system (system architecture at the most superficial level). The study was not taken to the level that would include specific algorithms.

AD-P005 436

AUTOMATION STRATEGY AND RESULTS FOR AN AIRBASE COMMAND AND CONTROL INFORMATION SYSTEM (ABCCIS)

by

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1. INTRODUCTION

Automation is considered the appropriate way to improve the effectivity of preparation and deployment of weapon systems in the increasingly complex scene of battle. This automation is aiming for the support of the activities, because, according to the opinion of the RNLAF, human intellectual capacity is essential to a balanced commercial and control process. Human intelligence and creativity combined with speed and storage capacity of the computer may improve the quality of the preparation and the effectivity of the deployment of weapon systems.

2. COMMAND AND CONTROL IN THE RNLAF

If we talk about "command and control" in Royal Netherlands Airforce this term deserves some explanation. This explanation is related to:
- objectives of the RNLAF,
- main tasks,
- hierarchical structure,
- readiness of operational units,
- airbase services,
- command and control process/C2 systems.

2.1 Objectives of the RNLAF

The mission of the NATO, in which organisation the Netherlands are participating with 15 other countries, is to maintain the status of peace and of international safety, and to stimulate the stability and the welfare in the North Atlantic area.

The contribution of the RNLAF to this mission is specified by the following objectives:
- defending the air space in the area of the NATO countries from agression (air defence);
- obtaining and maintaining the air superiority in the NATO command and control area (air defence, offensive counter air and air superiority);
- giving tactical support to the NATO land forces (close air support and interdiction);
- giving tactical support to the NATO naval forces in the allocated part of the North Sea and of the Channel (tactical air support of maritime operations and interdiction).

2.2 Main Tasks

The efforts in this framework form the main part of the tasks of the Royal Netherlands Air Force. To obtain a correct overview, it is important to recognize the coherence of these tasks and the related activities. A breakdown of the main RNLAF tasks yields the following overview:

a Air Superiority. The following mission types belong to the efforts aiming at air superiority:
- Air defence: air operations executed by aircraft and guided weapons in order to reduce or to nullify the effectivity of an hostile air attack;
- Offensive counter air: besides defensive contribution also offensive operations are needed in order to undermine the hostile offensive power;
- Air combat missions: offensive missions against airborne hostile aircraft, especially close to the battle-field.

b Tactical support by airforces. In the support of land and naval forces two types of operations can be distinguished:
- Close air support: this type of operations is directed mainly to hostile targets in the battle field area close to the own forces;
- Interdiction operations: concerning the land forces these interdiction operations have the intention to seal off the battle field by interrupting the connections and communications of the hostile land forces with their logistic and operational support facilities; concerning the naval forces the interdiction operations are directed to hostile surface vessels and harbour installations.

c Additional support operations: both the obtaining and the maintaining air superiority and the support of land and naval forces will be combined with additional air operations. These operations are:
- Air Reconnaissance: reconnaissance is executed by means of visual perception, and by sensors such as photographic, electronic, radar, television and infrared equipment;
- Air Transport: air transport facilities are deployed as well for transport of manpower as for logistics support.

2.3 Hierarchical structure

Also in peace time the command and control of the operational units of the Royal Netherlands Air Force is assigned to NATO-commanders. The forces in Central Europe are under the command of AFCENT, situated in Brunssum. The Central Region is divided into a northern and a southern sector; in both sectors an Army Group and an Allied Tactical Air Force (ATAF) are operating. Above these ATAF's an umbrella headquarter is functioning, Allied Air Force Central Europe (AAFCE) situated in Ramstein (Fig. 1).

2.4 Readiness of operational units

Besides the international centralization of the operational command and control, another essential aspect of the airforces is the high degree of readiness. This important capability of quick reaction gives a major contribution to the preventive task of NATO. Several elements can react within 5-30 minutes and all operational units have to be fully operational within a predefined time limit. These requirements are valid seven days a week and are evaluated several times a year via unannounced exercises. The high degree of readiness requires a quickly reacting process of command and control (C2-process) at -amongst others- the airbases of the RNLAF.

2.5 Airbase services

The services directly involved in the preparation and deployment of weapon systems on the airbase are:

* airbase command post; this is the center where all orders, from the next higher command level or self-generated, are coordinated and where the execution of the orders is monitored;
* one or more aircraft squadrons; there the key personnel related to preparation and deployment is available; main duties are the tactical preparation of the ordered missions and the real execution of these missions;
* logistics control post; this post is responsible for the aircraft preparation, as the provision of fuel and weapons;
* air traffic control; the local air traffic control service is in charge of the air traffic close to the airbase and is responsible for the take-off and landing sequence;
* ground defence command post; the main task is maintaining the readiness state of the airbase in such a way that the orders can be executed;
* communication service; this service is in charge of the communication aids and of the use of these aids.

The command and control lines will be discussed in the next paragraph.

2.6 Command and control process (C2)

The basic structure of the command and control process contains four elements:

- a commander gives orders from his headquarter;
- lower level headquarters (staffs) process the orders;
- a combat unit is tasked to execute the order;
- the results of the execution are reported to the commander via the same way.

Because orders may be sequential and because the command and control process oft has time-critical characteristics, the process has actually a cyclic structure (Fig. 2).

Nowadays the following definition of a C2-system is in use: "An integrated system consisting of doctrine, procedures, organization structure, personnel, equipment, infrastructural facilities and communication tools, that supplies timely and correct information to the commanders of all levels in order to give them the opportunity to prepare, to manage and to control their activities".

The basic form of a C2-system is represented in Fig. 3. The major part of the above defined C2-elements is available in the figure; the elements doctrine and procedures are invisible. It should be remarked that the weaponsystem is not a part of the C2-system. The aim of C2-systems can be summarized very concisely: to enable the authorities at all levels to manage the battle by supplying up-to-date, secure, trustworthy information.

The requirements for a C2-system should be match to the expected operational conditions. In the case of an airbase three types of circumstances are foreseen: peace time, times of tension and war time. Generally these requirements are:

- peace time : support of the air defence warning system by processing and analysing the sensor signals; monitoring of the intelligence situation and the status of the own resources; support of preparation and execution of exercises;
- times of tension: the peace time requirements are valid; moreover a quick information transfer to the higher commander is emphasized; the level of detail and the size of the [illegible]rect supply of information at all levels is important;
- war time : the requirements for peace time and times of tension are valid with the [illegible]hat exercise changes to reality; sufficient robustness is required to survive [illegible] actions and sufficient flexibility to assure continuity of command.

The command and control process is amongst others affected by developments in the following areas:

- speed of information transfer; although computer-based information systems are deployed, the speed of information handling is mostly determined by human activities and therefore - in comparison with other battle field developments - hardly improved (Fig. 4);
- armament; the range of armament is increased, the effectivity and the killing power are enlarged;
- electronic warfare; hostile electronic warfare troops and aircraft will try to disturb electronic communication and weapon systems;
- decision characteristics; a modern war is characterized by an abundance of information and dis-information; processing has to be tuned to the differences in priority and the time restrictions.

The most important bottlenecks with respect to the information flow in command and control information systems are:

- the poor interoperability within NATO;
- the low rate of automation in CCIS;
- the difficulties with the exchange of large quantities of information between computers;
- the limited effectivity of security measures.

3. AUTOMATION OF INFORMATION SUPPLY

The solutions of the above-mentioned bottlenecks are not yet fully available. It is clear that the upgrading of the degree of automation is necessary, possibly inescapable. But it is also necessary to make an inventory of advantages and disadvantages of automation. For this purpose a scheme will be used of the performance characteristics of information supply (Fig. 5). Although this scheme is drafted by the

Dutch National Aerospace Laboratory namely for development of computer based information system, it is also suited for the comparison between manual and computer-based information systems.

In the "Scheme of air tasks processing" (Fig. 6) a high-level overview is presented of the activities related to the preparations and deployment of weapon systems at airbase level as a consequence of an air task from the next higher command level. The "mission preparation flow chart" (Fig. 7) presents the air task message flow through the organisational structure of the airbase.

The information supply can be subdivided into five elements: acquisition (collection), storage, handling, distribution and presentation of information. With the help of these five elements the differences between manual an automated information supply can be explained in more detail.

- data acquisition ; information from elsewhere, local sensor data and local information collected manually. In the manual mode the sensor data is transferred only to the primary workplace, in the automated mode the data is available to anyone interested and authorised. Information from elsewhere arrives in books, lists and by telephonecall in the manual mode; if computers are applied, computer connections are used for data collection;
- data handling ; in the manual mode data handling is provided by people, in the automated mode by computers;
- data distribution; in manual information supply data is distributed by couriers, telex, telephone, in the automated situation by computer connections;
- data storage ; in the manual mode the storage media are wall totes, books, lists and maps, in the automated mode computer memory is applied.
- data presentation; in the manual mode the same media are applied as for storage, in the automated mode displays and printer are used.

The overview of the above mentioned differences between manual and automated information supply is given in Fig. 8.

3.1 Comparison of manual and automated information supply

The main performance characteristic (Fig. 5) of information supply is the trustworthiness: the rate in which a user can trust the information system for his information supply. This main characteristic is subdivided into five groups with the headings availability, continuity, integrity, accessibility and timeliness. The definitions of these headings are:

- availability: the rate in which the information supply is proof against non-intentional disturbances originating within the information system;
- continuity: the rate in which the information supply is proof against all interference or changes originating outside the information system, and against intentional interference originating within the information system;
- integrity: the rate in which the information corresponds with the reality that has to be represented;
- accessibility: the rate in which the information can be easily accessed within the restrictions of authorization;
- timeliness: the rate in which the time requirements are met (in relation to information supply).

During this presentation it is impossible and needless to consider all characteristics mentioned in the scheme of Fig. 5. Not all characteristics are equally relevant for the comparison. The complete list of definitions is given in Appendix A. During this presentation the feasibility of the requirements related to robustness, resilience, protectability, up-to-dateness, consistency and responsetime will be discussed. As far as exact figures are given in the description of the requirements, these figures are not yet validated. It is assumed that the figures approximate the real figures sufficiently for a realistic argumentation.

Robustness is defined as the rate in which the information system hardware is proof against all expected operational environmental conditions (shocks, vibrations, humidity, temperature, radiation etc.). The requirements related to robustness range from maximal one disturbance of maximum 8 hours uninterrupted within an operational period of 400 hours in peace time up to the war time requirement of maximal one disturbance of maximum 5 minutes uninterrupted within an operational period of 16 hours. Of course the manual system is less vulnerable than the automated system with his electronic parts. Especially the war time requirement with respect to the 5 minutes maximum down time is stringent. But also in the computer environment this requirement can be met, although the provisions are estimated to be expensive.

Resilience is defined as the rate in which the information supply can be continued after non-intentional disturbances originating within the information system. The requirements range from manual back-up with a reduced number of air tasks per time period in peace time up to war time requirements for automated back-up without intermission. Also the war time requirements with respect to the electronic systems can be realised.

Protectability is defined as the rate in which the information system is proof against all intentional interference and against non-intentional disturbances originating outside the information system. The peace time requirements concern measures against fire and lightning, the war time requirements also concern measures against shocks (caused by bombs), vibration and electromagnetic pulses. The problems related to shocks and vibration can be solved, the electromagnetic problem is under investigation.

Up-to-dateness is defined as the rate in which the information corresponds with the recent actuality. The acceptable time-lag depends on the type of information and on the circumstances. E.g. with regard to meteorological information: in peace time a time-lag of 3 hours is acceptable, in war time a lag of half an hour is permitted. It appears that these requirements can be met only by automated systems.

Consistency is defined as the rate in which coherent parts of information corresponds with each other. The requirements range from 1 error per 10.000 data elements in peace time up to 1 error per 10.000 data elements in war time. With computer support these requirements can be met.

Responsetime is defined as the time between an inquiry and a response to it at a terminal (determined by the queuing-time and the speed with which the inquiry is executed). The requirements related to responsetime for inquiries is 20-30 seconds, related to responsetime for modifications the maximum is

5 minutes. These requirements are valid in peace time and in war time. The feasibility of these requirements with respect to the manual information supply depends on the storage medium: in the case of wall totes the responsetime is almost zero, in the case of books the response times are not feasible. With respect to automated information supply the responsetime requirements can be met.

3.2 Conclusions

Although the comparison between manual and automated information supply is done only for some prominent performance characteristics, the conclusion may be drawn that advantages and disadvantages of manual and automated information systems arise from different performance characteristics. The major disadvantage of manual information systems is the low integrity of information; the major disadvantage of computer based information systems is the vulnerability of the electronics.

The trustworthiness of information supply requires as well sufficient availability and continuity as well as satisfying information integrity. Because the integrity of information in manual information systems cannot be further improved the attention should be paid to the decrease of the vulnerability of computer based information systems, especially to measures against electromagnetic interference.

4. AIR BASE COMMAND AND CONTROL INFORMATION SYSTEM (ABCCIS)

ABCCIS is the result of an incremental development by the Royal Netherlands Air Force and the National Aerospace Laboratory NLR. The RNLAF contribution is based upon its know-how of the actual ground operations and air operations. The NLR contribution is a logical extension of its knowledge on the military organisation, and of its experience with aircraft selection, operational evaluation, integrated combat training, and automation.

Technical features of ABCCIS are:

- Data structure
  * satisfies survivability, reliability, and security requirements
  * is in balance with high update rates.

- Processing modes
  * transactions: single updates, single information requests are processed immediately
  * batch: items are collected in groups before they are processed
  * interactive: is capable of man/machine interactions during engineering sessions.

- Presentation capabilities
  * alpha-numerical, graphic, and image-processing display units
  * alpha-numerical and graphics printer
  * colour and overlay facilities.

- Information arrangement
  * is adapted to the specific requirements of each user
  * offers predefined screen lay outs and is easily adaptable
  * is driven by control tables.

- Communication
  * is limited to point-to-point connections
  * offers reliability-based re-routing possibilities
  * is tuned to the existing communication network.

ABCCIS comprises the following four main subsystems (Fig. 9 and 10):

- Operations Management Information System (OMIS);
- Computer-Aided Mission Preparation System at Airbase Level (CAMPAL);
- Intelligence Information System at Airbase Level (INTAL);
- Meteorological Information System at Airbase Level (METAL).

4.1 Operations Management Information System (OMIS)

OMIS supports the processing of all order and messages related to the allocation of resources for air operations and ground operations. Therefore, all relevant status data are collected: information on pilots, critical personnel and equipment, war consumables, airbase, and alarm. These data are stored in the database and can easily be retrieved by the user. The central element of OMIS is constituted by the data management facilities; the specific user elements are dedicated to Air Task Processing at Airbase Level (ATPAL) and Ground Operations at Airbase Level (GROPAL).
OMIS is operational at two of the RNLAF airbases (see Fig. 11).

OMIS is equipped with (see Fig. 12):

- Off-line Support Packages for structuring the totes and the database and for evaluating the OMIS use and performance.
  * The Information Arrangement and Definition Package enables to select information to be presented in a rigid way (in view of security requirements). It supplies the tools for determining database cross sections and for arranging various screen layouts.
  * The Data Administration Package enables to maintain the database and the data dictionary. It supplies the tools for determining the structure of the database and the data dictionary, and for maintaining the database contents in case of approved changes in the database structure or data dictionary.
  * The Evaluation Package enables to survey the use and performance of OMIS daily. It presents the user errors, the frequency of requests for and updates of information per user, the mean and maximum wait and processing times per command, and the total number of information requests, updates, and other commands. Consequently, it is also a highly effective security tool.
- Data Management Facilities for efficient execution of the various management tasks related to the use and control of stored information.

- User Interface Package, which makes possible an adequate connection with the various application procedures.
- Application Procedures, such as ATPAL for air task processing and GROPAL for ground operations.

ATPAL supports the processing of all orders and messages related to the allocation of resources for air operations. It provides the means for monitoring the progress of the processing of air tasks, it ensures that the standard procedures are observed, and it reports the result of the operations.

GROPAL supports the ground operations by making available information concerning the alert status, the ground resources, the runway status, the NBC status, the local weather, etc.

4.2 Computer-Aided Mission Preparation at Airbase Level (CAMPAL)

CAMPAL supports the preparation of air-to-ground missions. It improves the preparation process through the easy availability of the most recent information on intelligence scenario, operational conditions, and aircraft and avionics status. The pilot consults the relevant data sources interactively. On a raster-scan colour monitor, the map data are displayed together with route information. CAMPAL consists of two main functional parts: for navigation and for threat evaluation.
CAMPAL is operational at one of the RNLAF airbases in a prototype version, and can be deployed for both war- and peace-time mission preparation.

This computer-based information system:
- speeds up the preparation by automation of standard procedures;
- improves the preparation through the easy availability of the most recent information, based on the specific weapon-system characteristics and the ever changing circumstances;
- facilitates the preparation because the pilot can interactively consult (no computer knowledge required) various relevant data sources (Intell, standing procedures, meteo, geographic) before taking his decisions;
- strengthens the preparation by automatically assessing the threat figures using the complex, quickly changing intelligence scenario in full detail;
- is validated in F-16 operations in the European scene.

The process is controlled via the alpha-numerical display of the interactive workstation. For the actual route determination, the workstation includes a tracker ball. The digitizer serves as an additional input means. On a raster-scan colour monitor, the map information and related data are displayed. These data can be printed via the colour hardcopy unit. The graphic printer shows all planning results other than the navigation maps, such as the navigation-system (INS) data, the weapon-system (SMS) data, the alpha-numerical navigation information for the Combat Mission Folder, and general mission data.

The interactive workstation is supported by a VAX 11/780 mini-computer. This computer can serve at least three such workstations. See for the current operational hardware configuration Fig. 13.

4.3 Intelligence Information System at Airbase Level (INTAL)

INTAL supports the collection and processing of the intelligence data, such as order-of-battle information, target information, threat data, and the like. It assists the expert in obtaining an integrated view on the various aspects of a war situation, including the threat on route and in the target area. For presentation purposes, both alpha-numerical and graphic display facilities are available.
An INTAL pilot system is currently installed in an operational environment (see Fig. 14).

4.4 Meteorological Information System at Airbase Level (METAL)

METAL supports the collection and processing of the meteorological data, obtained from various sources. It assists the expert in obtaining an integrated view on the weather situation in the area of the operations. It adapts these data for easy and efficient usage during the mission preparation and it offers local weather information.
At the moment, the CAMPAL raster-scan colour monitor is used for presentation of the weather information during the pilot's mission preparation.

5. CONCLUDING REMARKS

The experiments with the ABCCIS subsystems in the operational environment have proved that the use of automation tools with respect to information supply improves the integrity of the information and facilitates the mission preparation.

The bottlenecks with respect to the vulnerability characteristics of computers must be eliminated to improve the resistance of electronic information system against war violence.

Up to now the automation concerning ABCCIS is directed to information supply mostly ~~(Fig. 15)~~. The state-of-the-art of automation offers more possibilities to improve the information handling rate. The most important possibilities are:
1) - extension of the decision and information handling support;
2) - condensation and upgrading of information;
3) - knowledge engineering.

These items are the elements of the mission preparation system of the pending future, (Fig. 16).

APPENDIX A
Definitions of Performance Characteristics of Information Supply

Accessibility
The rate in which the information can be easily accessed within the limits of authorisation.

Adaptability
The rate in which changes in the reality to be represented can be easily incorporated into the information system.

Auditability
The rate in which improper - sometimes fraudulent - modifications of the information can be detected and remedied.

Availability
The rate in which the information supply is proof against non-intentional disturbances originating within the information system.

Communicativity
The rate in which the information system can exchange information with other systems.

Consistency
The rate in which the coherent parts of information correspond with each other.

Continuity
The rate in which the information supply is proof against all interference or changes originating outside the information system, and against intentional interference originating within the information system.

Correctness (implementation)
The rate in which the implementation satisfies the user requirements.

Correctness (information)
The rate in which the information is without errors.

Frequency
The number of times a specific process has to be repeated within a pre-defined time range.

Imperturbability
The rate in which disturbances in the information supply can be prevented after interference caused by modifications/changes in the information system.

Integrity
The rate in which the information corresponds with the reality that has to be represented.

Operability
The rate in which instructions can be easily given to the system (in number and type of actions).

Protectability
The rate in which the information system is proof against all intentional interference and against non-intentional disturbances originating outside the information system.

Quality
The rate in which the whole of characteristics of a product, process or service satisfies the requirements, derived from the objectives for usage.

Readiness
The rate between the speed with which the information system presents information after the moment the information is defined in case of shared usage of resources and the speed in case of non-shared resources.

Recoverability
The rate in which the information supply can be restarted after repair.

Reliability
The probability that an information system can execute the required functions under pre-defined circumstances in a specific time range.

Repairability
The rate in which malfunctions in the implementation and in the carrier-hardware can be easily detected and remedied.

Resilience
The rate in which the information supply can be continued after non-intentional disturbances originating within the information system.

Responsetime
The time between an inquiry and a response to it at a terminal (determined by the queing-time and the speed with which the inquiry is executed).

Robustness
The rate in which the information system hardware is proof against all expected operational environmental conditions (shocks, vibrations, humidy, temperature, radiation, etc.).

Screenability
The rate in which unauthorised inspection of information can be prevented.

Security
The rate in which the information supply is proof against (non-)intentional access, inspection, usage, modification, destruction, and disclosure.

Speed
The time rate in which a pre-defined process is executed.

Survivability
The rate in which the information supply can be continued after interference exceeding the defined protectability.

Timeliness
The rate in which the time requirements are met (in relation to information supply).

Trustworthiness
The rate in which a user can trust the information system for his information supply.

Up-to-dateness
The rate in which the information corresponds with the recent actuality.

User-friendliness
The rate in which the interface between information system and user is tuned to the procedures, discipline and experience of the user.

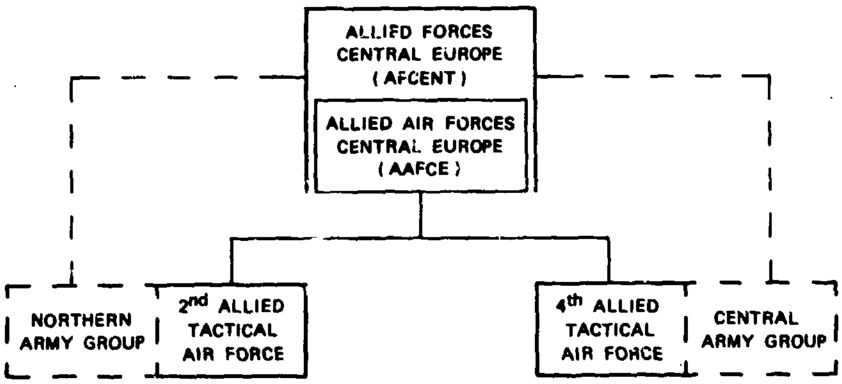


Fig. 1 Structure allied forces in the "Central Region"

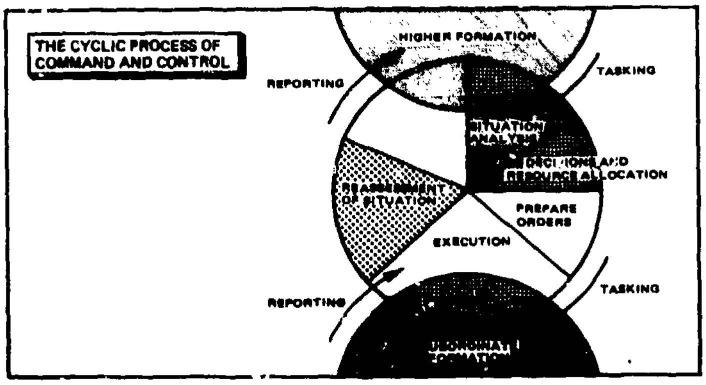


Fig. 2 C2-cyclus

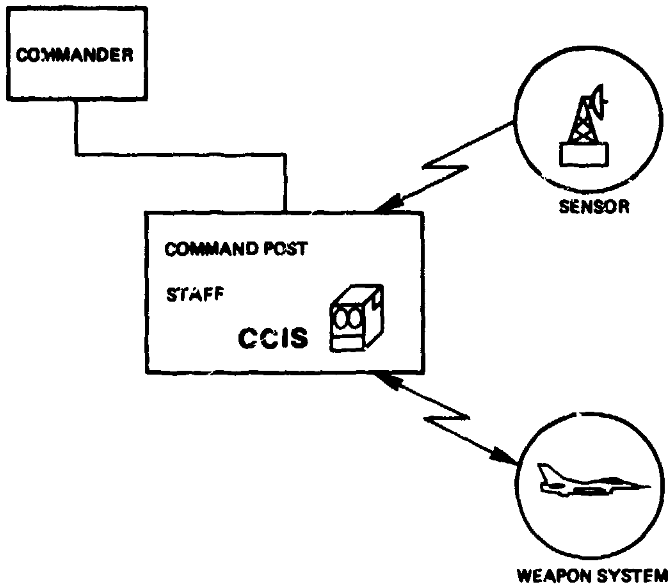


Fig. 3 Elements of a C2-system

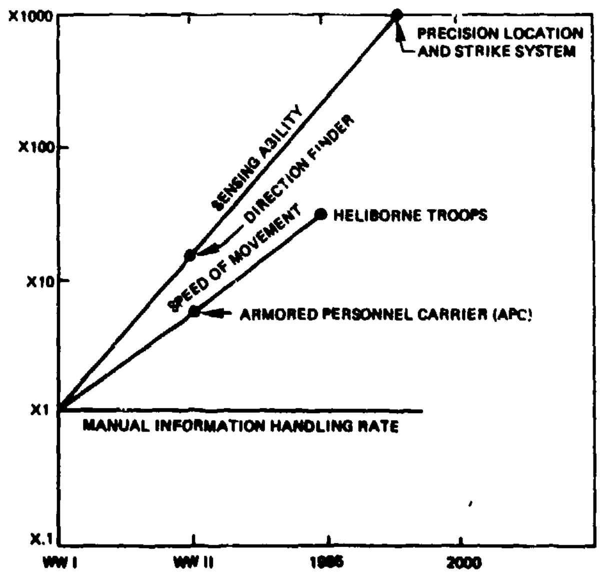


Fig. 4 "Improvement of information handling rate, related to other battlefield trends

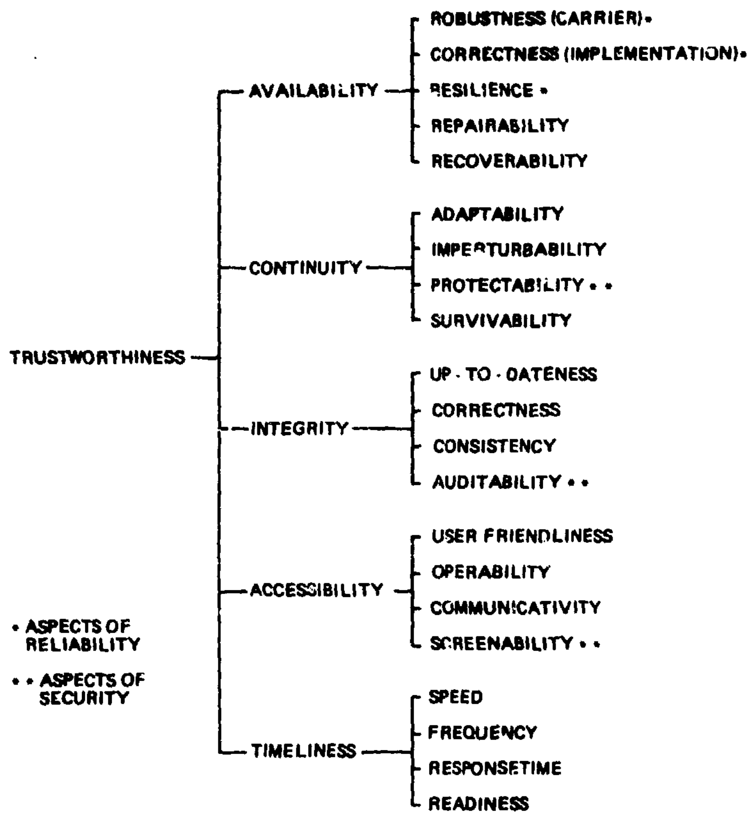


Fig. 5 Scheme of performance characteristics for information supply

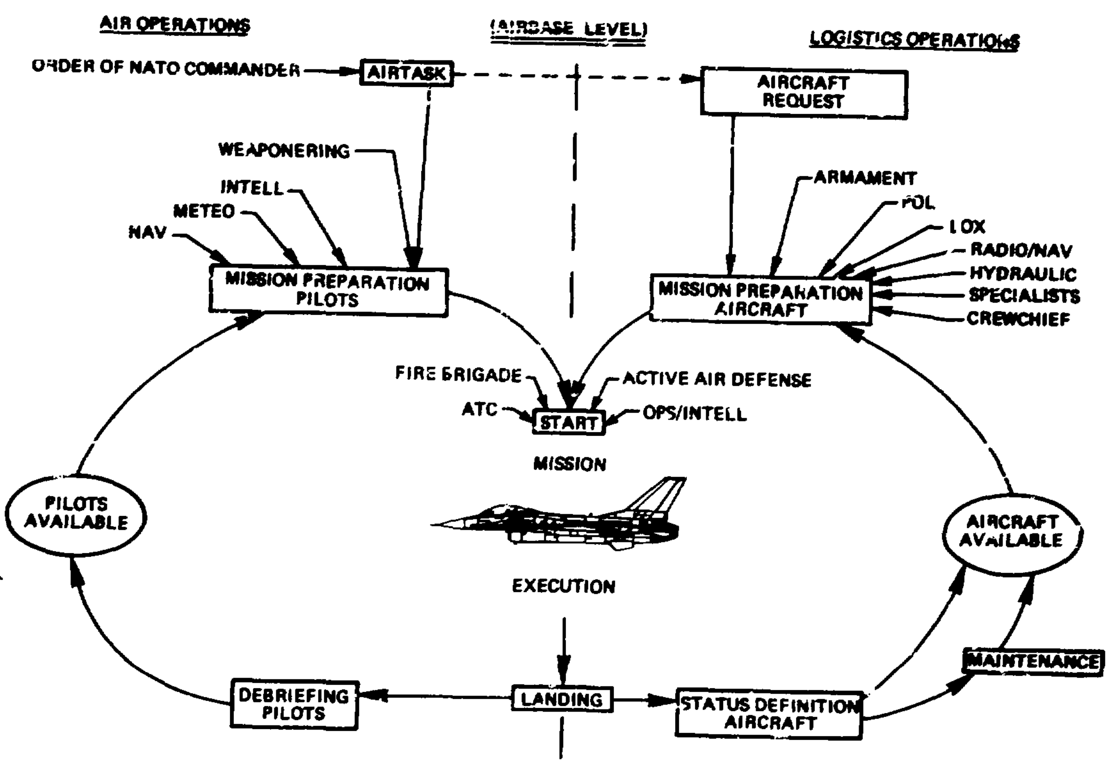


Fig. 8 Scheme for air tasks processing

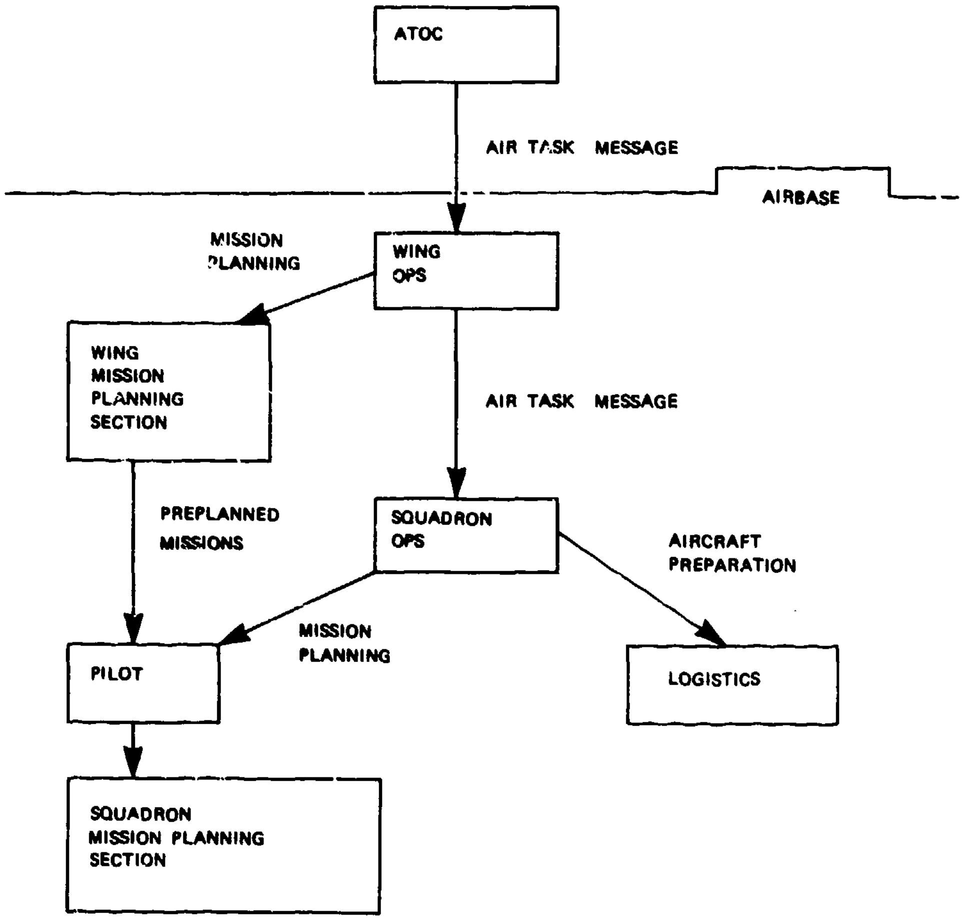


Fig. 7 Mission flowchart

ELEMENTS		MANUAL INFORMATION SUPPLY	AUTOMATED INFORMATION SUPPLY
ACQUISITION (COLLECTION)	SENSOR	AT ONE PLACE AVAILABLE	UIVERSALLY AVAILABLE
	FROM ELSEWHERE	BOOKS, LISTS, TELEPHONE	COMPUTER CONNECTIONS
	LOCAL	PEOPLE	PEOPLE
HANDLING		PEOPLE	COMPUTERS
DISTRIBUTION		TELEPHONE, COURIERS	COMPUTER CONNECTIONS
STORAGE		WALL TOTES, BOOKS, MAPS, LISTS	COMPUTERMEMORY
PRESENTATION		SAME MEDIA AS FOR STORAGE	DISPLAYS PRINTERS

Fig. 8 Differences between manual and automated information supply

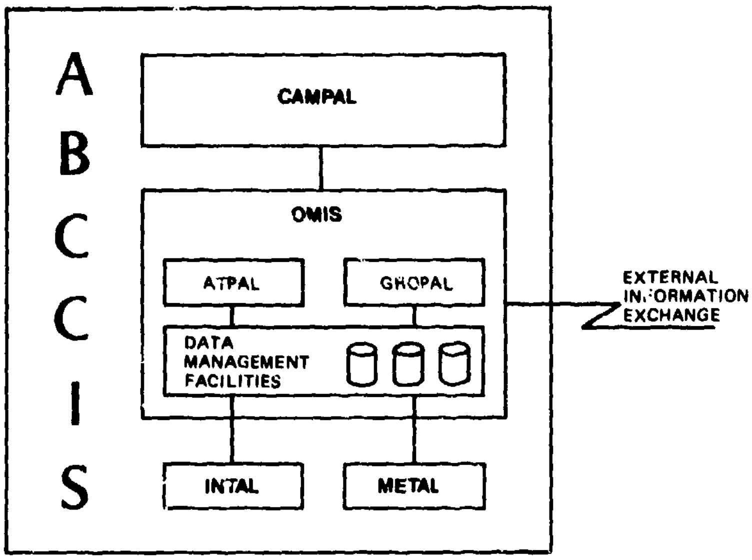


Fig. 9 Coherence of ABCIS-subsystems

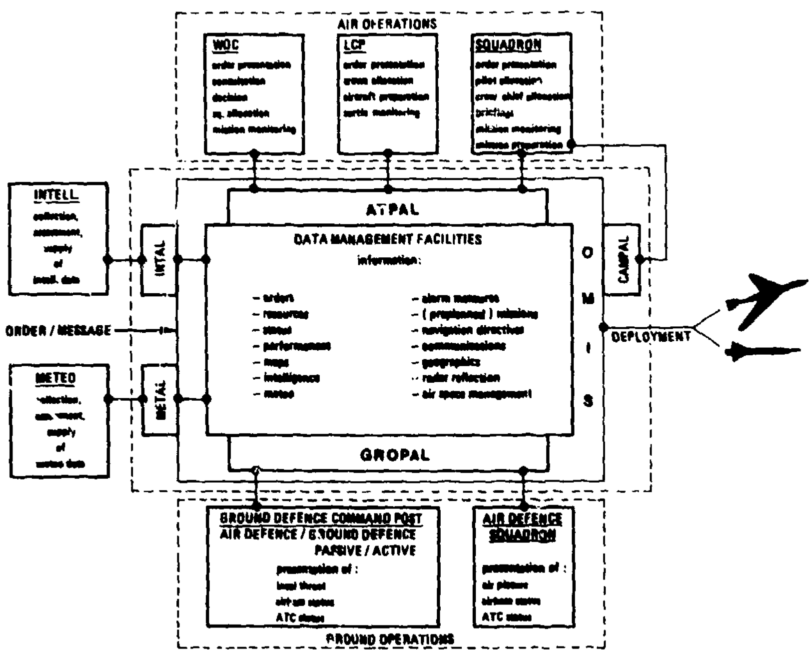


Fig. 10 Overview oi ABCCIS usage

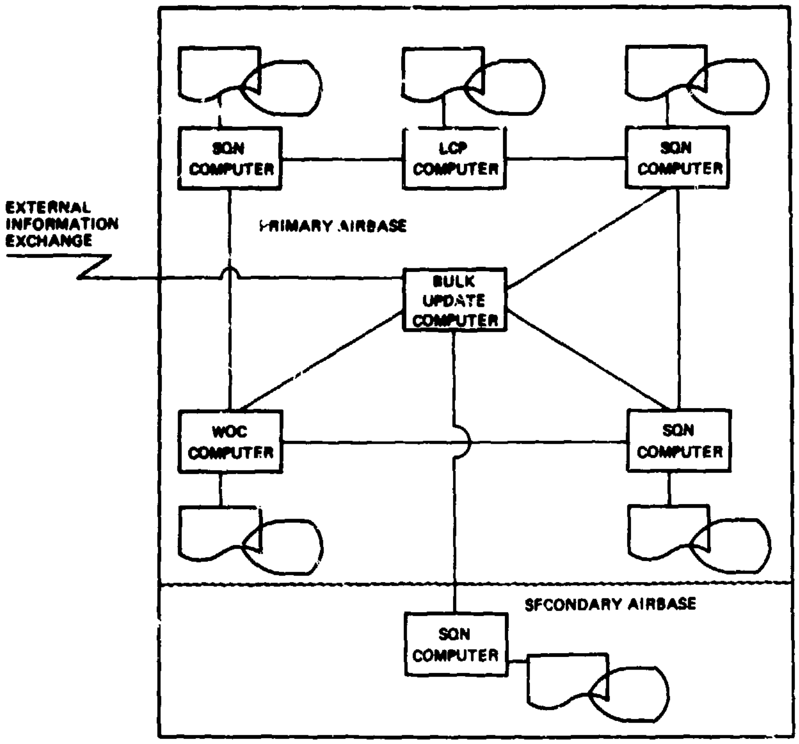


Fig. 11 Typical ONIS configuration

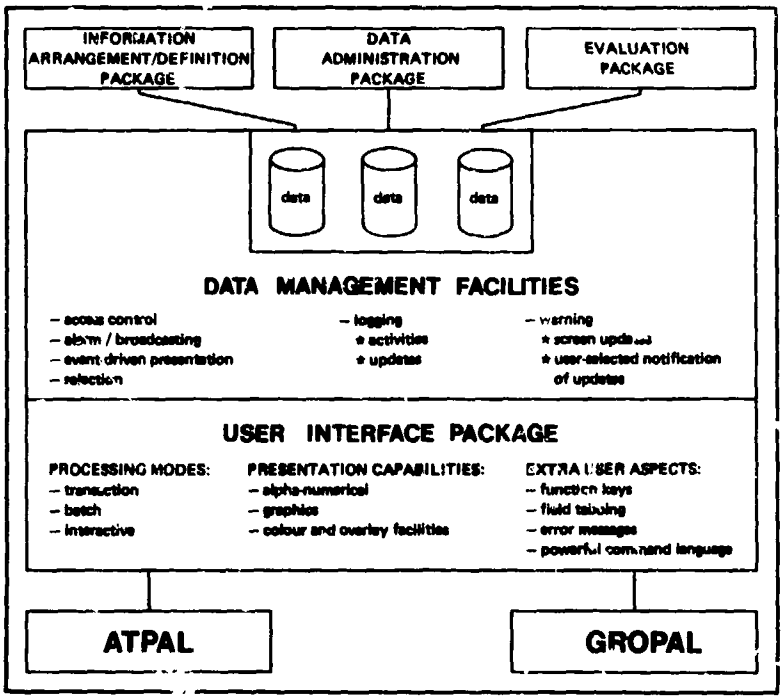


Fig. 12 Overview of ONIS-functions

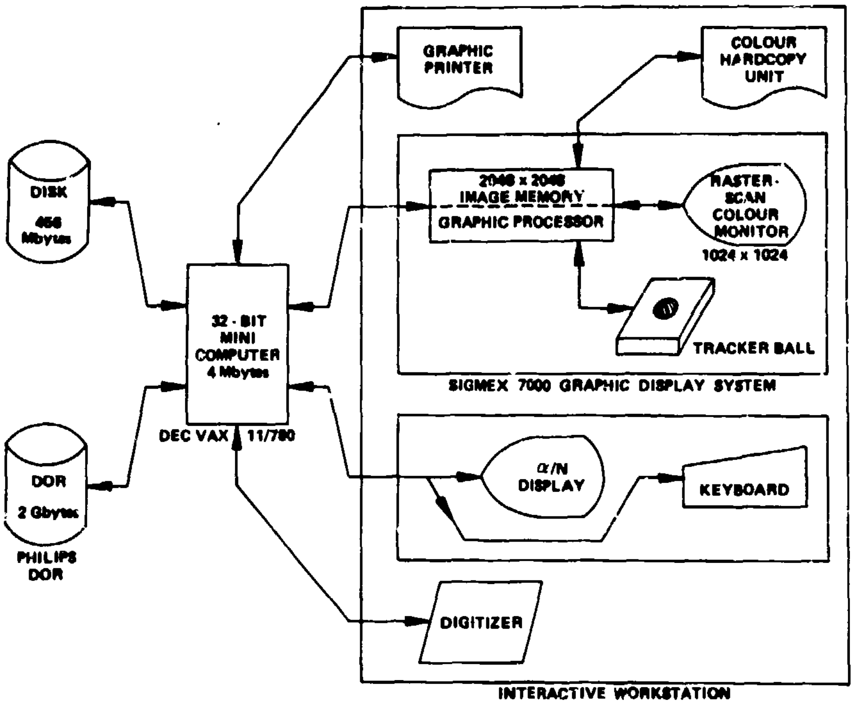
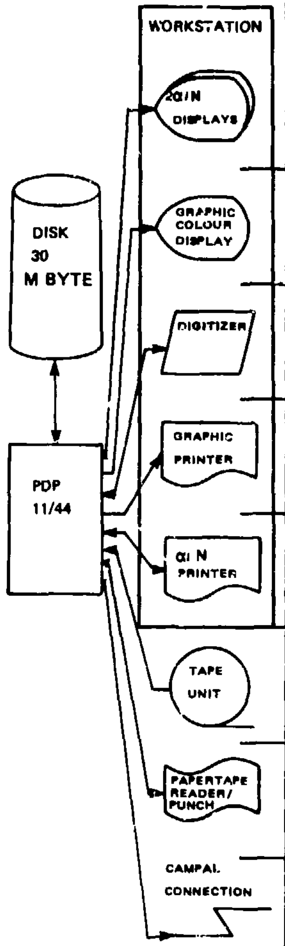


Fig. 13 Current CAMPAL configuration at Royal Netherlands Air Force Base



Device	CO ECTION	ASSESSMENT	SUPPLY
αl N DISPLAYS	ON PAPER PRESENTED INFORMATION	CONTROL OF ASSESSMENT, REFERENCES AND ADDITIONAL INFORMATION	
GRAPHIC COLOUR DISPLAY	PLAUSIBILITY CHECK	USER SELECTABLE COMBINATIONS OUT OF SEVERAL INFORMATIONSOURCES	
DIGITIZER	GEOGRAPHIC RELATED INFORMATION		
GRAPHIC PRINTER		INTERMEDIATE GRAPHIC RESULTS	EFINGS
αl N PRINTER		INTERMEDIATE αl NRESULTS	HARDCOPY OF ADDITIONAL INFORMATION
TAPE UNIT	BULK SOURCE INFORMATION		
PAPERTAPE READER/ PUNCH	INSTANT CHANGES ON SOURCE INFORMATION		REPORTS
CAMPAL CONNECTION			PROVISION OF RELEVANT INFORMATION ON REQUEST

Fig. 14 Current INTAL hardware configuration and its usage

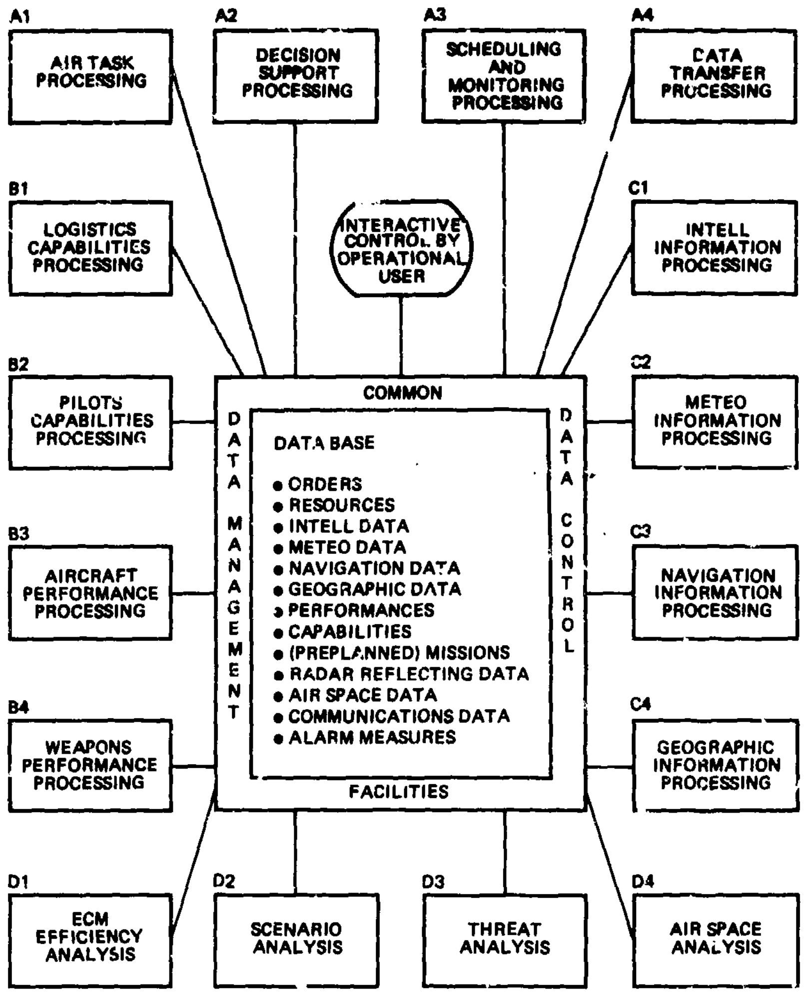


Fig. 15 Architecture of mission preparation information system

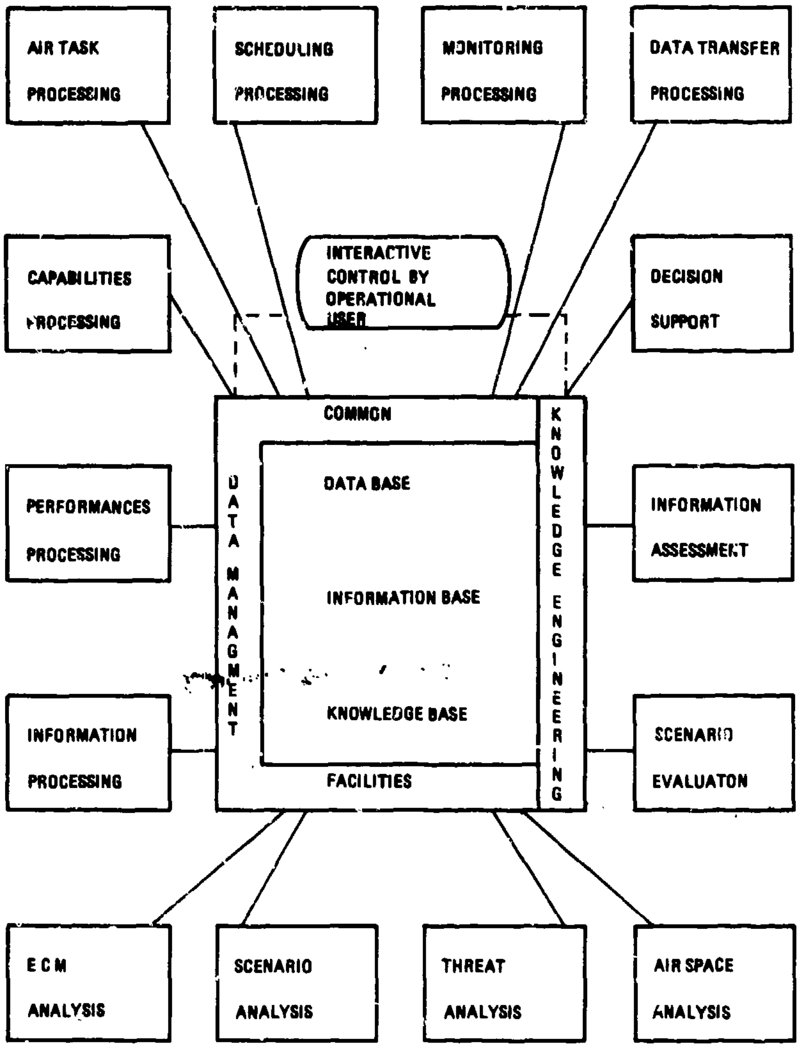


Fig. 16 Future architecture of mission preparation information system

DISCUSSION

S. Boehmer, USA
How is the database updated? Manual, floppy disk, automated.

R.P. de Moel
Bulk data via magnetic tape (from AAFCE), small updates manually.

J.H. Powell
How will the system interface with European wide data systems such as EDDS (European Data Distribution System).

R.P. de Moel
The system is linked to EIFEL, the next higher level system at ATOC.

AD-P005 437

TARGETING AND WEAPONS REQUIREMENTS IN CLOSE AIR SUPPORT STRIKE OPERATIONS

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USA

INTRODUCTION

This paper presents a Naval Weapons Center study on close air support (CAS) targeting requirements and systems. The paper gives an overview of U.S. Marine Corps CAS and identifies problems in specific areas of the CAS mission, including threat, communications, timing, target marking, and target acquisition. The study also analyzes CAS targeting requirements and formulates guidelines for improvement of CAS targeting capabilities.

MISSION DEFINITION

Close Air Support

CAS is defined as air action against hostile targets that are in the proximity of friendly forces. Detailed integration of each air mission with the fire and movement of the friendly forces is required.

Close-in Fire Support

The support furnished to ground troops by Marine Corps attack helicopters is called close-in fire support (CIFS). The same coordination with ground and air forces is required. The CIFS mission is different from CAS in force structure and ordnance employed, but is included in this study since it is also air support provided to ground troops.

Target Acquisition

Target acquisition is the term used to indicate the process of locating the target once the general target area has been entered. The target acquisition process usually begins with some type of search; includes detection, recognition, or identification; and ends when the weapon has been released, fired, or locked onto the target. The use of "acquire" in this report denotes whatever task (or tasks) is appropriate in the context of the discussion.

The unique functions in CAS of air-to-ground communications and targeting marking can also be included as part of the target acquisition process. A target marker (e.g., smoke, panels, or a laser designator spot) could also be thought of as the first of two targets in the search process, with the target itself the final objective.

STUDY METHOD

This study was carried out in three phases:

1) Review of CAS studies, handbooks, operational reports and instructor materials, with weighting given to analysis and experience over the last eight years.

2) Interviews with U.S. Marine Corps (USMC) aviators.

3) Synthesis of information gained from the literature and from interviews as the basis for identification of the problems, their causes, and possible improvements in CAS targeting.

The study is qualitative in nature; assumptions and important factors in CAS target acquisition are simply stated with quantitative supporting data. These statements are generally agreed to in the operational and technical communities. Conclusions as to target acquisition requirements can be derived from the statements, and these sets of requirements can form the "shopping list" for choices of targeting device development.

SCOPE

Most of the target acquisition functions required of Marines in combat are given in Table 1, where the components (or "players") are also listed. The table shows the wide range of operations that include some form of target acquisition. Items were reduced in number to those predominant in the air-to-ground attack, CAS mission (Table 2). Table 3 further restricts the scope of Table 2 to items most appropriate to targeting per se.

TABLE 1. Complete Classification of Target Acquisition Spectrum.

I. Ground-to-ground

a. Components:[a]

1. Ground troops (e.g., infantryman, forward observer)
2. Vehicle crews (e.g., Dragon gunner)
3. Artillery crews

b. Functions:[a]

1. Acquire/track enemy before firing
2. Direct fire on enemy
3. Designate enemy (e.g., with a laser device or smoke marker)
4. Report enemy location

II. Ground-to-air

a. Components:

1. Troops
2. Antiair weapon units (e.g., Hawk unit)

b. Functions:

1. Acquire friendly cargo helicopters (helos)
2. Acquire friendly forward air controllers (airborne) (FAC(A))
3. Acquire friendly attack aircraft
4. Acquire enemy air (helo and jet)

III. Air-to-air

a. Components:

1. Helos
2. FAC(A)/tactical air coordinator (airborne) (TAC(A))
3. Fighter aircraft
4. Attack aircraft

b. Functions:

1. Acquire enemy aircraft
2. Acquire own aircraft

IV. Air-to-ground

a. Components:

1. Cargo helos
2. Troop helos
3. Attack helos
4. FAC(A)
5. Fighter/attack jets

b. Functions:

1. Acquire own forces
2. Acquire landmarks (e.g., control points, identification points)
3. Acquire target marker
4. Acquire target
5. Acquire landing site

[a] Numbers assigned to components and functions are not necessarily correlated.

TABLE 2. CAS Target Acquisition Functions.

Other functions in the CAS operation are not included here (e.g., acquiring enemy aircraft).

I. Ground-to-ground

a. Components: Troops

b. Functions:

1. Direct fire
2. Designate target
3. Report target location

II. Ground-to-air

a. Components: Troops

b. Functions:

1. Acquire own FAC(A)
2. Acquire own attacker

III. Air-to-air

a. Components:

1. Helos
2. FAC(A)
3. Fighter/attack jets

b. Function: Acquire other friendly aircraft

IV. Air-to-ground

a. Components:

1. Attack helos
2. Fighter/attack jets
3. FAC(A)
4. Ground support (FAC, air support radar team)

b. Functions:

1. Acquire own forces
2. Acquire target marker (e.g., smoke, laser spot, radar beacon)
3. Acquire landmarks
4. Acquire target

TABLE 3. Study Priorities in CAS Targeting.

I. Air-to-ground

a. Components:

1. Fighter/attack jets
2. Attack helos
3. Observer aircraft

b. Functions:

1. Acquire target
2. Acquire target marker
3. Designate target (from air or ground)

II. Ground-to-ground

a. Components: Troops

b. Function: Designate targets

Two other important functions are closely related to an attack aircraft pilot finding the target: communications and marking the target (Table 4). These two areas are treated explicitly in this study since they have been key components in the CAS target acquisition process and are not found at all in other types of air-to-ground target acquisition.

TABLE 4. Additional Functions in CAS Targeting.

I. Communication

a. Components:[a]

1. Tactical Air Command Center (TACC)
2. Direct Air Support Center (DASC)
3. Fire Support Coordination Center (FSCC)
4. TAC(A)
5. FAC(A)
6. Ground support (FAC, air support radar team)
7. Attack aircraft

b. Functions:[a]

1. Request air strike
2. Direct aircraft to target area.
3. Pass target and strike information
4. Mark target
5. Clear aircraft for strike, or abort strike
6. Coordinate timing

II. Mark/designate target

a. Components:

1. Troops (FAC, artillery crew)
2. FAC(A)
3. Fighter/attack aircraft

b. Functions:

1. Locate targets
2. Launch marking munition
3. Track and designate target
4. Estimate or measure range and bearing to target
5. Describe target location to FAC(A) or attack aircraft
6. Time target marker properly

[a] Numbers assigned to components and functions are not necessarily correlated.

THE CAS MISSION

This section gives a broad overview of the Marine Air CAS and CIFS missions. A number of studies have been conducted, and handbooks and trial reports are available that provide a great amount of detailed information on threats, weapons, targets, and their associated tactics. Since the information is available, only its essence need be repeated here.

Aircraft

The principal attack aircraft involved in CAS will be the AV-8B, A-6E, and F/A-18. (The A-4M and F-4N/3 will be used in the reserve forces.) The OV-10 is the aircraft in use by FAC(A) in the Marine observation squadrons. The AH-1J/T is the attack helicopter that provides CIFS. Two of the attack aircraft are single-place types, so the pilot will be heavily task-loaded in the CAS environment. The A-6E, F-4S/N, and AH-1J/T have two crewmen, so there will be sharing of the work.

Threats

The major threats will be mobile weapons that include the ZSU-23-4, small arms and automatic weapons, and several varieties of surface-to-air missiles (SAMs). Air threats from enemy fighters are also a possibility, and Hind helicopters could be a threat in some scenarios. The threats will use radar as well as electro-optical and infrared (EO/IR) sensors to locate and track the Marine aircraft. The specific location of the threats may not be known ahead of time, because of their mobility.

Targets

Most of the targets in the majority of the CAS scenarios will also be mobile - tanks, armored personnel carriers (APCs), and vehicle-mounted artillery. Targeting the threats themselves (ZSU-23-4) would also be effective. If the Marine ground forces are attacking, such things as fortifications (bunkers) could also become targets.

The vehicular targets are considered "point" targets (as opposed to area targets), whose location can change because of their mobility. This type of target is not easy to see unless it is raising dust in a dry environment, or is marked or designated by a FAC or FAC(A).

Environment

The Marines could encounter a broad range of environments; e.g., flat, open country with little vegetation; hilly country with little vegetation or covered with trees; open farmland; or built-up coastal regions, including urban areas. Operations must be performed day and night in all seasons. Limited visibility and low ceilings make air operations difficult. Night conditions make operations more difficult, but also decrease the threat's effectiveness by disrupting optical tracking.

An additional environmental problem that must be considered in weapon employment studies is jamming. It is likely that air-to-ground communications will be degraded by jamming. Radar performance will be degraded by jamming by both sides in a conflict.

The identifying feature of both CAS and CIFS is operation in proximity to friendly troops. Traditionally, this has required close communication between the ground troops and their attack aircraft. First, and most important, by good communications ground troops can ensure that their own troops are not attacked; second, they can ensure that the desired target is attacked and destroyed. A jammed environment makes this communication difficult if not impossible at times.

Tactics

Basic weapon delivery tactics are dictated by the aircraft capabilities, weapon characteristics, weather, and the threat. The weapons must be delivered within the range envelope (between a maximum and a minimum range) and in some cases must impact at a high enough grazing angle to be effective. The release conditions must be such that the aircraft can avoid weapon fragmentation. Weapon fragmentation from the first aircraft in a strike must be avoided by the second aircraft. (Timing is critical.)

The threat forces the aircraft to fly such that target acquisition is difficult and weapon delivery is not in the "optimum" part of the envelope. Jet aircraft fly as low and fast as possible. They make frequent turns to make tracking them difficult (jinking). They use terrain masking to avoid detection. This same masking keeps them from seeing the target, of course. Helicopters fly as low as possible, avoid any populated area, and also use all the masking possible.

Jet aircraft must normally increase their altitude before weapon release, entering a shallow dive or loft maneuver, or popping up and then entering a shallow dive over the target. Some weapons can also be delivered in a low-level loft (e.g., 10-degree pull-up to release) if the target can be found in time.

Helicopters conducting CIFS usually use the pop-up maneuver, search the area for the target, slew the weapon or turn the helicopter, lock on (if appropriate), track and fire. Sometimes tracking is required after weapon launch. This pop-up takes them just above the terrain- or vegetation-unmask point.

The timing of the attack pass is critical, particularly when target marking and mobile targets are involved. This coordination between the ground FAC, any airborne FAC, and the attack aircraft may also take place in a high-threat, communications-jammed environment (in the worst-case situation).

Target marking can take many forms, depending on the aircraft systems and whether the strike is at night or in the daytime. Smoke has been used for years to cue the pilot where to look for the target, or where to release the weapons if the target cannot be seen. White phosphorous (WP) smoke can be delivered from the ground or in the air (other colors are not now available).

The development of laser designators, laser spot trackers, and laser-guided bombs and missiles has provided a new capability in CAS target acquisition and attack. These laser devices provide two functions: they cue the pilot and the aircraft system to the target's location, and they provide an aimpoint for the laser-guided weapon. Cueing reduces the pilot's search time, and guidance reduces the weapon's circular error probability (CEP).

TARGETING OVERVIEW

The material presented above is intended to give a flavor of some of the target acquisition aspects of close air support, without repeating much of the detail available in other reports.

CAS has a wide variety of flight profiles (medium altitude, low altitude, pop-up, etc.), weapons, and players. CAS must be conducted at night, in the daytime, and in all sorts of terrain and weather. Jets, observation aircraft (OV-10s), and helicopters engage in direct support of the ground troops (CAS and CIFS).

CAS has some of the same target acquisition problems that are found in strikes away from friendly troops (e.g., haze, masking, battlefield clutter, weather). The additional requirements to locate and communicate with friendlies near the targets, and to mark the targets, introduce additional problems. The ability to mark the targets, however, can make things easier for the attack pilot. It appears that all these requirements must be met in a medium- to high-threat environment.

TARGETING PROBLEMS

More small mobile targets will be encountered in CAS than in deep-strike attack missions. Because of their mobility, the locations of these targets will not be known exactly, and they will be "available" to attack for only a short time. Mobile targets are difficult to locate, unless marked, and they may be heavily defended.

The proximity of friendly troops brings good news and bad news. The bad news is that it is very important that the attack pilot not drop his weapons on the wrong target. His task-loading is increased by having to locate the enemy and, at the same time, know he is not threatening to friendly troops. He can't just drop his payload on, or shoot at, anything that looks man-made.

The good news is that those nearby friendly troops can mark themselves and the targets to aid the attack aircraft. The type of marking must fit the situation and be compatible with the aircraft systems.

Table 5 shows the most favorable conditions for CAS. Many of these conditions might be found in a permissive environment, against an unsophisticated enemy. However, current scenario or mission-description documents state that most of these conditions should not be expected.

TABLE 5. Optimum Conditions for CAS.

1.	Accurate aircraft navigation system (good to 100 meters)
2.	Target marking or cueing visible to pilot or avionics sensor (laser spot tracker), and accurate offset from marker to target
3.	Marking of own or friendly troops visible to aircraft
4.	Good air-to-ground communication with adequate time available for message
5.	Clearance by FAC before weapon release
6.	Positive identification of target by pilot before release
7.	Damage assessment and second-pass instructions from FAC after weapon delivery (for new aimpoint from marker)
8.	Good timing between air and ground
9.	Appropriate aircraft weapons, tactics, and target (proper warhead, fuze, impact angle, etc.)
10.	Accurate weapon release computer

Table 6 shows some of the problems that an aircrew might have in actually finding the target once all the other problems have been surmounted. These problems are caused by the target's characteristics (generally, hard to see or to locate with radar or forward-looking infrared (FLIR) sensor) and by the threat forcing the aircrew to fly low and, for jets, fast.

TABLE 6. Problems in Target Acquisition.

Problem	Cause
1. Small targets	Targets are mostly vehicles (tanks, APCs, ZSUs).
2. Low-contrast targets	Targets use dirt, foliage, paint, and camouflage to avoid detection.
3. Fleeting targets	Targets are mobile.
4. Restricted visibility	Natural weather, battlefield smoke restrict visibility.
5. Terrain and vegetation masking restrict visibility	Low-flight altitude of aircraft in order to avoid threat.
6. Short search time	Threat forces high speed, single pass, or quick pop-up by aircraft.

Target marking increases the probability of the aircrew's finding the target and reduces search time to a minimum in a high-threat environment. Table 7 shows some problems with the employment of target markers. As shown in the table, there are problems with both a simple system like smoke and a complicated and expensive system like a laser designator. The laser designator also requires reliable laser tracker avionics in the aircraft.

LASER DESIGNATOR USE

A laser designator used as a marking device is precise. It is also active, and can be used (in reverse) to indicate where the forward observer is. The aircraft must be equipped with a compatible sensing system, which must be pointed in the right direction to detect the laser spot.

Use of a laser-guided weapon has one large advantage: it decreases the CEP; however, it can make other tasks in the weapon delivery process more difficult. Coordination and timing are more difficult. And the designator, whether ground or airborne, is more vulnerable than passive systems. The half-life of a designator is not very long.

An obvious need is to decrease the designation time required by our acquisition systems and by laser weapons.

TABLE 7. Target-Marker Acquisition Problems.

Problem	Cause
1. Smoke marker not always visible.	Battlefield haze, smoke. Restricted visibility. Wind blows smoke away. Not usable at night or in snow because of color.
2. Smoke marker not unique.	Enemy counters with own smoke. Colored smoke is not available, but needed.
3. Smoke marker is static.	Smoke cannot "follow" moving targets.
4. Smoke marker may not be placed accurately near target.	Inaccuracy in marker delivery, artillery firing of marker round, or communication.
5. Laser designator readiness unknown (both ground and airborne).	Operator cannot see designator spot on target.
6. Laser designator vulnerable (both ground and airborne).	Long time (10 to 30 seconds) required with spot on target (depending on tactic and weapon system).
7. Wrong laser designator and laser tracker codes sometimes used.	Poor communication makes coordination difficult.
8. Laser designators difficult to use at night.	No night sighting devices for ground laser units.
9. Target markers not visible from low-flying aircraft.	Terrain and vegetation masking.

Table 8 shows some additional targeting problems that would be encountered during night operations. The A-6E target recognition and attack multisensor (TRAM) and the F/A-18 with its FLIR would not require flares, but use of the aircraft radar system with a radar beacon, and the FLIRs will still not be easy in a high-threat environment.

TABLE 8. Night CAS Problems.

	Problem	Cause
1.	Aircraft must fly higher at night than in the daytime.	Automatic terrain avoidance systems (if any) not totally relied on.
2.	Flare illumination difficult.	Pilots do not want to overfly target to drop flares. Flare placement not accurate. No forward-firing flares in Marine Corps inventory.
3.	Location of target by ground FAC difficult at night.	Night search and ranging systems are not now available.
4.	Target acquisition (search) by airborne sensor alone is not likely.	Restricted field of view, aircraft and target location uncertainty, low flight altitude, time limitation.
5.	Use of a ground beacon alone is not good enough for target strike.	Range and azimuth from beacon to target can be inaccurate.
6.	Location of identification point (IP) at night for pop-up attack is difficult.	IPs are usually visual fixes. Most current aircraft do not have a good enough navigation system.

ASSOCIATED PROBLEMS AND SOLUTIONS

It is unrealistic to consider the target acquisition function as an independent item in the CAS process. Related processes and problems that might be considered to be outside, or on the fringes, of targeting are shown in Table 9. These factors certainly affect the ability of the aircrew to find the target.

TABLE 9. Communication and Coordination Problems.

	Problem	Cause
1.	Unrestricted air-to-ground communication probably not possible.	Enemy jamming. Low-level flight makes communications difficult.
2.	Description of target location takes a long time, if possible at all.	Different views of target area from air and ground. Description not precise.
3.	Split-second timing difficult (precise time-on-target).	Poor aircraft clocks and navigation systems. Enemy diversions, bad weather.
4.	Timely target designation for weapon delivery difficult.	Mobile targets have a short exposure time. A multiple-aircraft strike complicates coordination and communication.

Figure 1 is a block diagram of the interrelated factors for a fixed set of conditions that an operational group would face in wartime. The only feedback loop shown goes from "effectiveness" to "tactics." In a given campaign, the military forces must operate against a specific threat and target, with the aircraft, avionics, and the marking devices available in the inventory. The only factor they can change is tactics if they are not satisfied with their effectiveness. Some recent tactics changes have had good success in countering threats and communications jamming.

Figure 1 also illustrates the "associated" solutions to the targeting problem. If aircraft avionics are changed to improve survivability (e.g., improved chaff), the tactics could be changed to improve target acquisition capability (e.g., fly higher). If a target-marking device on the ground is changed to improve target acquisition capability and thereby improve effectiveness, aircraft avionics could remain the same. And so on.

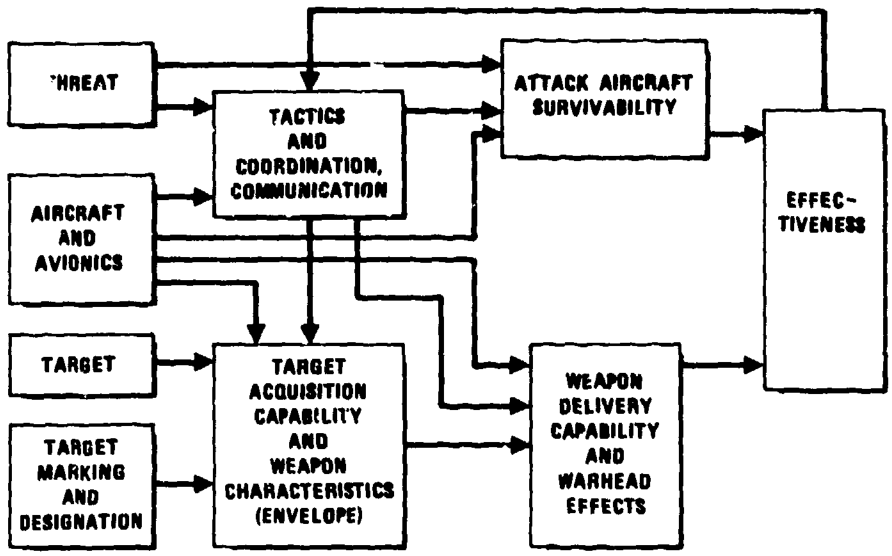

FIGURE 1. CAS Factors for Fixed Set of Equipment and Environmental Conditions.

TARGETING IMPROVEMENT GUIDELINES

A good targeting development strategy would include the following:

1. The targeting must be successful under flight conditions that are necessary to deal with the threat (e.g., low altitude, high speed).

2. The targeting performance should be compatible with the delivery envelopes of the available weapons (e.g., a minimum range of 6,000 feet).

3. Operation of the targeting system must not increase the aircrew work load since it is already too high.

Information reviewed during this study indicates that the threats will remain high and probably increase in intensity. Today's less-developed cultures will soon have sophisticated antiair weaponry, so the "low-threat" environment may be a thing of the past.

One approach is to integrate targeting, electronic countermeasures, and weapon developments that would attack the target and threat (sometimes the same) as a system. If the threats can be detected, located, and killed or suppressed, attacking other targets becomes much easier. And until the threats can be suppressed, CAS may well be an unacceptable mission, because of unacceptable attrition rates.

PRELIMINARY RECOMMENDATIONS

What would be the most important improvements in USMC Air CAS ability, from the targeting standpoint? The following seem to predominate in all of the above descriptions:

1. Improved threat acquisition and suppression

2. Improved communication in the jammed environment

3. Improved target marking

4. Improved friendly marking

5. Improved target acquisition, per se.

6. Decreased aircraft and target designator exposure time

What proposed "improvements" may not help much? A listing should include:

1. Proposals for improving or modifying current, often expensive, products without clearly showing what the improvement will buy.

2. Longer-range weapons that do not deal with the associated severe long-range target acquisition problem (especially over land).

3. Concepts that do not deal with the threat and cannot be used at very low altitudes or at high speeds (for jets).

4. Concepts that purport to increase the target acquisition range (e.g., through better resolution), but do not solve the masking-from-low-altitude or very-short-exposure-time problems.

5. Concepts that increase aircrew decision-making and work load.

6. Concepts that are not compatible with our current and near-future weapons and their envelopes.

SUMMARY

This paper has briefly described CAS operations and identified some of the target acquisition problems. Discussion of associated problems such as communications has also been included. Some general recommendations have been made on areas needing immediate attention, and a strategy for longer-range development has been suggested.

The information contained in this study is intended to be used in combination with a technology survey to produce specific hardware development proposals.

TENUE A JOUR DE SITUATION PAR SYSTEME EXPERT

par

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PRESENTATION GENERALE

Depuis plusieurs années, l'Armée de l'Air française procède à l'équipement des centres d'opérations en moyens de traitement automatisés. La description d'un tel système d'aide à la décision : celui dont est dotée la Force Aérienne Tactique, fait l'objet d'un exposé ici même.

Dans ce contexte, les équipes de réalisation ont été amenées très tôt à s'intéresser aux possibilités qu'apporte une approche par les moyens de l'Intelligence Artificielle. La planification des missions, la gestion des ressources sont des domaines où ces techniques sont naturellement utilisables. Le renseignement militaire également et nous allons ici présenter une application concernant la tenue à jour d'une situation par système expert.

Après cette description nous évoquerons certaines conclusions auxquelles nous a conduit la réalisation de systèmes experts dans le domaine des C3I.

L'AUTOMATISATION DU TRAITEMENT DU RENSEIGNEMENT

Un centre d'exploitation du renseignement militaire a pour tâche de rassembler le maximum d'informations possibles sur les forces adverses, de les traiter (corrélation, interprétation, validation), de les stocker, de réaliser des synthèses et de les présenter sous des formes diverses en vue de leur utilisation opérationnelle. L'ordre de bataille (OB) constitue une des présentations les plus courantes de de type de situation.

En temps de paix, les informations recueillies concernent en général des unités dont le stationnement est relativement stable. Un traitement manuel des observations recueillies est suffisant.

En temps de crise ou de conflit l'ordre de bataille des forces adverses devient très évolutif. Pour tenir la situation à jour il faut traiter chaque jour un grand nombre d'observations provenant de sources très diverses : compte rendu de missions pour les observations à vue, exploitation des reconnaissances aériennes (photo, optronique infra-rouge, radars SLAR, etc...) ou des renseignements fournis par les satellites, etc... Par ailleurs, la tenue à jour de cette situation doit se faire pratiquement en temps actuel pour être en phase avec le déroulement des opérations aériennes.

A l'évidence, un traitement informatique de toutes ces données est indispensable pour exploiter dans les délais voulus la masse des informations reçues.

Le système automatisé de traitement du renseignement militaire, appelé VIGILE, propose de répondre à l'ensemble des besoins du 2ème Bureau en temps de paix, de crise ou de guerre : établissement et gestion des dossiers d'objectifs, mise en forme et actualisation permanente des ODB, élaboration des plans de recherche du renseignement, etc...

Le projet VIGILE prévoit de traiter les différentes fonctions par des algorithmes spécifiques. Cependant le développement des systèmes experts permet d'envisager de les utiliser pour traiter de façon plus élégante et plus efficace un certain nombre de problèmes.

L'Intelligence Artificielle est en effet particulièrement bien adaptée au domaine du renseignement :

- possibilité d'utiliser les connaissances spécifiques d'un certain nombre d'experts de haut niveau au profit d'opérateurs rapidement formés (réservistes en temps de guerre),

- traitement d'une grande masse de données,

- langage conversationnel simple, fournissant à la demande les explications voulues sur le processus de raisonnement du système et expliquant ses déductions.

- possibilité de modifier la base de connaissances pour introduire de nouveaux matériels ou modifier les caractéristiques de ceux déja pris en compte,

ODB ET SYSTEME EXPERT

Le système VIGEX se propose d'appliquer la technique des systèmes experts sur un cas concret simple : établissement de l'ODB (déploiement) des systèmes de défense aérienne d'un Corps d'Armée adverse à partir des informations recueillies par différents capteurs sur une période de 9 heures au jour J + 2 d'un conflit : observations visuelles des pilotes, exploitation des reconnaissances aériennes et des photographies prises par des satellites, renseignements de guerre électronique.

Il s'agit de savoir, avec la plus grande fiabilité possible, comment les systèmes d'arme sol-air ennemis sont répartis sur le théâtre d'opération. Ceci permettra, éventuellement à un autre système-expert, de préparer la mission aérienne sur ce théâtre, d'évaluer la menace,...

L'utilisation de VIGEX a été conçue pour être aussi conviviale que possible et pour permettre ainsi l'accès à des personnes n'ayant aucune formation en informatique par l'utilisation de graphiques, de menus et d'une interface en langage naturel.

Le but de VIGEX conduit le système à remplir des types de fonctions distinctes :

. la saisie manuelle aidée des informations ponctuelles émanant des organes de recherche spécialisée, identifiées au préalable comme pouvant appartenir à des éléments SAM,

. la corrélation automatisée des informations saisies avec les informations stockées ;

. la présentation à l'utilisateur pour validation de :

  * la création de nouveaux éléments,
  * la modification d'éléments,
  * la mise en attente d'information non corrélable,
  * l'élimination d'éléments ;

. la présentation d'une situation des moyens sol/air afin de préciser leur localisation (ODB) ;

. la déduction, à partir de cette situation, d'une hypothèse de déploiement;

. une aide à la compréhension des résultats obtenus ;

. la prise en compte par l'expert de la modification des modèles de déploiement des unités, ou des types de système d'arme.

Pour effectuer sa tâche, VIGEX dispose, à l'entrée, d'une série "d'observations" ponctuelles et incomplètes sur le déploiement ennemi ; ce sont les constituants initiaux de sa base de faits. VIGEX dispose aussi de la description de toutes les configurations possibles pour chacun des "systèmes d'arme" ainsi que la description d'un certain nombre de "déploiements types" des forces ennemies. Ce sont les constituants de la base de connaissance.

FORMALISATION DE LA CONNAISSANCE

La base de connaissance est structurée de la façon suivante :

- règles de production,

- frames de déploiement type,

- frames de système d'arme.

En effet, un système d'arme est composé d'un certain nombre de caractéristiques (véhicule de tir, fréquence d'émission radar,...) qui peuvent prendre chacune certaines valeurs. De même, un modèle de déploiement est une mosaïque de zones géographiques distinctes, chacune pouvant contenir un type donné de système d'arme. Pour pouvoir décrire ces deux types de connaissance, le formalisme "frame" était bien adapté.

Par contre, pour résoudre les problèmes suivants :

. quel modèle de déploiement essayer en premier ?

. quel est le meilleur positionnement de ce modèle par rapport aux emplacements des observations ?

. etc...,

les règles de production sont les mieux adaptées.

FORMALISATION DU RAISONNEMENT

Le raisonnement en "chaînage-avant" consiste à partir des observations à trouver à quel système d'arme elles correspondent puis à chercher à quel déploiement type correspondent ces systèmes d'arme.

Le raisonnement en "chaînage-arrière" consiste à faire l'hypothèse d'un déploiement-type puis, pour chacun des systèmes d'arme qui le constituent, à voir si il y a, au même emplacement, des observations qui y correspondent.

SAISIE D'UNE OBSERVATION

Une observation se présente sous la forme d'une suite d'informations sur les caractéristiques d'un système observé et/ou détecté (mais non forcément reconnu), précédée de deux clés :

. lieu de l'observation,
. type de l'observation (à vue, photo, guerre électronique etc...).

La saisie se fait par l'utilisation d'une grille comportant toutes les caractéristiques envisageables des matériels pris en compte dans la base de connaissance du système.

Il suffit à l'utilisateur de remplir chaque caractéristique, une par une, pour rentrer en machine de façon systématique et complète les informations qu'il possède.

CORRELATION DES INFORMATIONS

Le déploiement des systèmes d'armes sol/air est caractéristique du déploiement d'un type de Corps d'Armée, suivant les modèles que peuvent établir un 2ème Bureau.

Le système VIGEX, pour chaque point géographique concerné, établit la corrélation des différents renseignements recueillis. En cas d'identification certaine (i.e d'une plausibilité suffisante) d'un type de matériel, il affiche sur l'écran un symbole fixe correspondant à ce matériel. Dans le doute il affiche simplement un point d'interrogation dans l'attente d'informations complémentaires ou d'une décision de l'opérateur.

Si les identifications déjà effectuées permettent de positionner le schéma type du Corps d'Armée ou l'OBD des systèmes sol/air, l'opérateur ou le système pourront en tenir compte pour lever le doute sur les batteries non identifiées ou identifiées avec un mauvais coefficient de certitude.

LANGAGE NATUREL

Le module de langage naturel est chargé de gérer la compréhension de phrases tapées par l'utilisateur et de présenter la réponse à la question ou d'exécuter l'ordre correspondant.

Ce module est capable de comprendre des phrases tapées sous un grand nombre de formes syntaxiques. Il peut également comprendre les formes abrégées ou grammaticalement incorrectes.

Le module de langage naturel analyse la phrase entrée à l'aide d'un arbre syntaxique pour en déduire la réponse à fournir ou l'action à effectuer.

3 Il est capable d'un certain auto-apprentissage. Lorsque l'utilisateur lui donne une forme grammaticale nouvelle, il recherche la plus proche parmi celle qu'il connaît.

RESUME

En résumé, VIGEX est un système expert qui établit le déploiement probable des systèmes d'arme d'un corps d'armée à partir des informations recueillies par différents capteurs de renseignements.

VIGEX dispose en entrée de plusieurs types d'informations :

- des observations incomplètes et de qualité variable, provenant de sources de renseignements diverses,

- les caractéristiques des principaux systèmes d'arme,

- les modèles de déploiement des forces ennemies.

VIGEX propose deux modules d'interface :

- l'un créé pour l'expert : il permet de rentrer les modèles de systèmes d'arme et les modèles de déploiement,

- l'autre destiné à l'utilisateur : il permet de rentrer les observations recueillies par les divers capteurs et de demander à VIGEX de déduire de celles-ci le déploiement le plus proche de la réalité.

VIGEX met en oeuvre plusieurs techniques de l'Intelligence Artificielle :

- représentation de la connaissance sous forme de "frames" et de règles de production,
- prise en compte et exploitation de données floues avec affectation de coefficients de crédibilité,
- exploitation d'une interface homme-machine en langage naturel.

VIGEX est implanté sur machine SUN. Il est développé en LISP et langage C.

Dans les mois qui viennent, VIGEX va évoluer notamment sur deux points.

Il va d'abord être compléter de façon à suivre l'évolution d'une situation d'heure en heure. La comparaison des déplacements successifs permettra ainsi de constater le renforcement ou l'attrition du système global de défenses sol/air et de formuler des appréciations sur les déploiements des unités.

Par ailleurs, pour rendre la relation homme-machine encore plus aisée, des essais vont être faits pour commander VIGEX à la voix.

SYSTEME EXPERT : LES RISQUES

La mise en place d'un système expert dans le domaine du Renseignement militaire et plus généralement des C3I présente un certain nombre de problèmes spécifiques.

- Le risque d'agression extérieure

  Le savoir-faire introduit dans un système expert est une matière chère. Elle a en effet parfois été coûteuse à formaliser. Dans tous les cas, l'ensemble représente un capital opérationnel important.

  Qui plus est, ce capital est ici parfaitement bien isolé et structuré (la base de connaissance). Son interprétation en est donc a priori plus aisée et plus rapide.

  Il importe donc à chaque fois de prendre les mesures physiques et logiques pour protéger ces systèmes des risques d'intrusion et de capture.

- La tentation de la facilité

  Dès lors que l'on simule un comportement de raisonnement avec un système expert, le risque existe de lui faire progressivement une confiance de plus en plus grande. Ce risque est naturellement plus élevé en période de crise où les utilisateurs sont soumis à des stress de toutes sortes (nombre élevé de messages, décision à prendre rapidement etc...).

  Il faut donc veiller à bien préparer l'emploi opérationnel des systèmes expert pour laisser nettement la prise de décision aux utilisateurs et à leur esprit critique. C'est en particulier comme cela que l'on peut se protéger des risques de pollution des bases de données et des systèmes par l'adversaire.

SYSTEME EXPERT : L'INTERET

Un des principaux avantages de l'approche système expert est d'ordre méthodologique et concerne tant les experts opérationnels que les réalisateurs de C3I automatisé.

Pour les experts opérationnels, participer à la conception d' un système expert, c'est l'occasion de formaliser, de structurer son savoir-faire. Ce travail peut conduire à une consolidation, voire à une remise en cause de certains mécanismes de raisonnement et de prise de décision. Cette tâche est importante par ces conséquences et son ampleur.

Réaliser un système expert c'est également formaliser, rationnaliser, les relations et les échanges d'informations entre experts et équipes de réalisation du C3I.

Pour les réalisateurs, on doit considérer que l'approche système expert n'est pas nécessairement une fin en soi. Un système expert est également un outil de conception et de maquettage de système automatisé. En effet, le système expert sépare clairement le savoir-faire (base de connaissance) de l'animation informatique (le moteur d'inférence). Il constitue donc une structure qui se prête plus aisément à modification que des programmes classiques.

Il devient donc alors possible, par une succession de démonstrations prototype, d'arriver rapidement à une bonne conception du système à automatiser c'est-à-dire qui intègre correctement et dans tous les détails les mécanismes de raisonnement concernés.

AD-P005 438

COMPUTER AIDED SENSOR PLACEMENT OPTIMIZATION

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SUMMARY

The problem of optimal sensor placement increases with the mobility of the sensors. New threats e.g. caused by new missile technologies lead to sensor systems, where some of the sensors are highly mobile. Thus the optimization of sensor placement for a given surveillance area becomes a complex and time critical task if constraints such as

- own operations areas,
- terrain ondulation,
- terrain accessability,
- sensor capabilities,
- own tactical objectives, and
- assumed tactical objectives of the WP forces

have to be taken into account.

This paper presents a layer model for the computer aided stepwise optimization of sensor placement respecting the restrictions mentioned above. The computer tool is based on digitized terrain data containing information about the height and culture (fields, trees, roads, water, houses etc.). The layer model is based on interactive procedures and automatic decision guidance. The software can be installed on minicomputers with a color display and color printer thus making it a mobile transportable tool which can be used online in the field.

1. PREFACE

In recent years ESG has gained a lot of experience with computer tools for the simulation of radar sensors and the production of radar coverage diagrams based on digitized terrain data with terrain resolutions of between 30 and 1000 meter per pixel. The output of the coverage diagrams is either by an electrostatic plotter on transparent paper for full scale map overlays or by a color graphics terminal connected to a color printer which produces handy diagrams and also maps on paper or transparent foils for overlays or viewgraphs. The software was originally installed on a CDC 6000 and later implemented on a DEC VAX 11 and an IBM 4341 Computer.

A fictive example of a coverage diagram is given in Figure 1. It shows the overlay of an airborne line-of-sight sensor coverage (upper diagram) and a fictive radar station coverage on top of a mountain with jammer and clutter effects (lower diagram). The corresponding maps (originally colored) to underlay the coverage diagrams are shown in Figures 2 and 3. These are shadow maps to represent the surface structure (Figure 2) and color coded height maps (Figure 3). The tool was used in the NATO Air Command and Control Systems (ACCS) project for the ACCS Multi Sensor Integration Study (AMSIS). In this project some hundred radar coverage diagrams for existing and planned radar sites were produced.

The fast development in computer hardware with increased and cheaper storage and faster processing time now allows to install the tool on minicomputers, thus making it portable and mobile. With these features it is possible to use it not only for studies but also for field applications.

2. THE OPTIMIZATION TOOL

Our customers very often expressed the wish for a tool which not only simulates the coverage of a given radar at a given radar site, but in addition helps in the optimization of its placement. This lead to the development of a tool which is a good compromise between high technical performance and low computation time on the one hand and on the other hand allows to determine step by step an optimum sensor placement. It is based on an overlay of different layers representing decision criteria such as terrain, technical and tactical criteria.

2.1 The Reverse View

The most important initial step is to find positions from which the areas of interest can be observed by the sensor. It was decided not to use the maximum percentage of coverage as the decisive criterium but to define some points of interest e.g. in the magnitude 3 or 4 which should be seen by the sensor. These points might represent roads or flight corridors through which an enemy attack could be expected. The reason for the decision against the maximum percentage coverage is illustrated by Figure 4 and 5.

Furthermore this concept allows a fast computation of suitable sensor positions. This is done by a socalled reverse view rest elevation calculation. To explain this let us first explain the term rest elevation. Figure 6 illustrates the way how for a certain target height above ground, the coverage diagram can be computed from the rest elevation. Given a certain sensor position and height above ground the rest elevation is defined by the height above which the target can be seen. For a given terrain as shown on top of the

figure the rest elevation is given below. The rest elevation is always positive or zero. If it is zero, the ground can be seen.

A coverage diagram is obtained by coloring these areas where the rest elevation is smaller or equal to the target height. It is also possible to divide the rest elevation in several intervalls and display it color-coded.

Normally, one coverage diagram shows the area which is seen for a given sensor position. In optimizing a sensor position we face the inverse problem. We compute for each of the points of interest, which serve as the optimization, the reverse view rest elevation, which is the rest elevation (line of sight) as seen not to but from these points. The areas where all rest elevations of the points of interest are zero, are possible sensor locations from which the sensor sees these points of interest. If no such area exists we can display the area for which all rest elevations are below e.g. 100 meters. Figures 7 illustrates this principle.

2.2 Layer Structure

Thus the a.m. reverse view coverage diagrams define terrain layers for the decision process. Other terrain layers may result from a requirement that the sensor must be neither above water nor within a village, an information which is contained in the culture data of the terrain file. By intersecting the layers these areas (water, villages etc.) are blanked out from the potential sensor placement areas.

As far as the technical criteria are concerned we may know the position and strength of jammers for electronic counter measures (ECM). These define layers of areas which should be avoided, thus reducing the potential area for sensor placement even more.

Another technical criterion may be that an area with a slope above a certain value is not accessible for the sensor. Other areas may be blanked out by manually entering their contours with a light pen. E.g. these areas are technically or orographically unaccessible.

Tactical criteria might e.g. be not to position a sensor beyond a certain battle line or on top of a hill despite of the better coverage. Such constraints may be entered manually or by computer aids. This tool interface is suitable for implementation of artificial intelligence procedures.

The intersection of the above mentioned layers defines areas which best fulfill the optimization criteria. Each layer is stored in the color terminal's image memory and occupies 1 bit per pixel. Entire layers can be switched on and off or colors can be attributed to them (see Fig. 8).

2.3 Selection of Sensor Site

In the areas were the sensor placement criteria are best fulfilled one or more positions are selected manually and their radar coverage diagrams are calculated respecting all the sensors radar features. Thus an optimal placement can be found quickly and its coverage diagram is available in color on the screen and as a color hardcopy from the printer.

3. CONCLUSION

Optimal sensor placement is a complex task involving human experience (e.g. tactical considerations) and mathematical calculations (e.g. covered area for a given digitized terrain). It is generally recognized that it is very difficult and unprecise even with a lot of experience to predict the coverage for a given sensor position just by regarding a map with its elevation contour lines.

Thus computerized tools based on a digitized terrain elevation and culture data base become a very successful means for optimizing sensor placements.

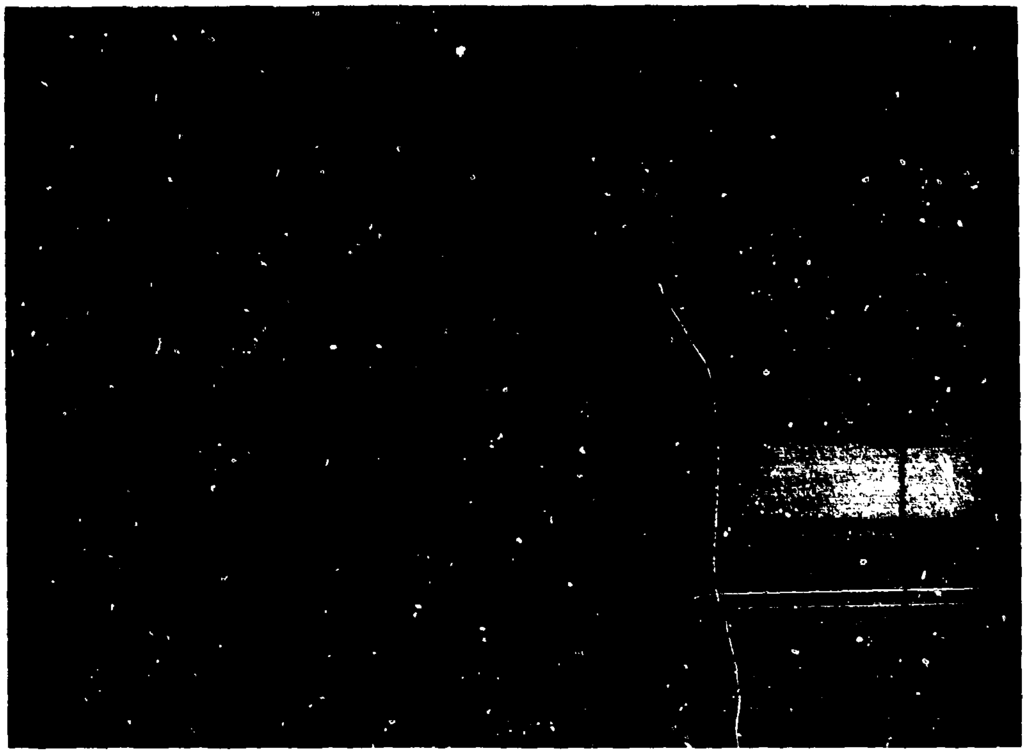

Figure 1: Coverage Diagram

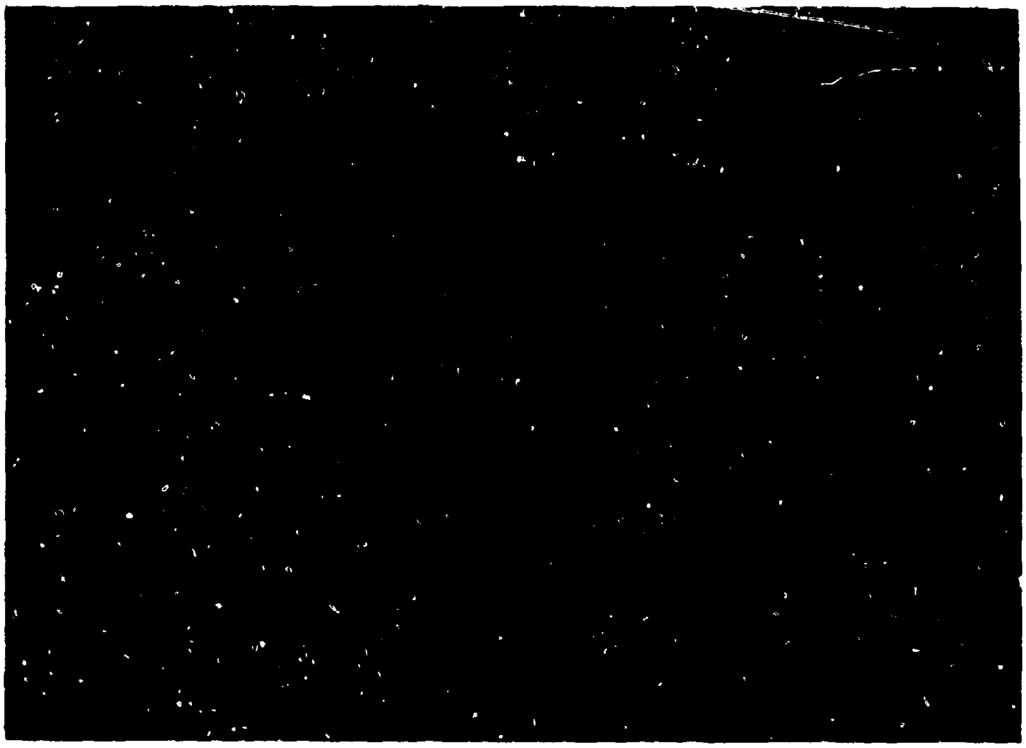

Figure 2: Shadow Map

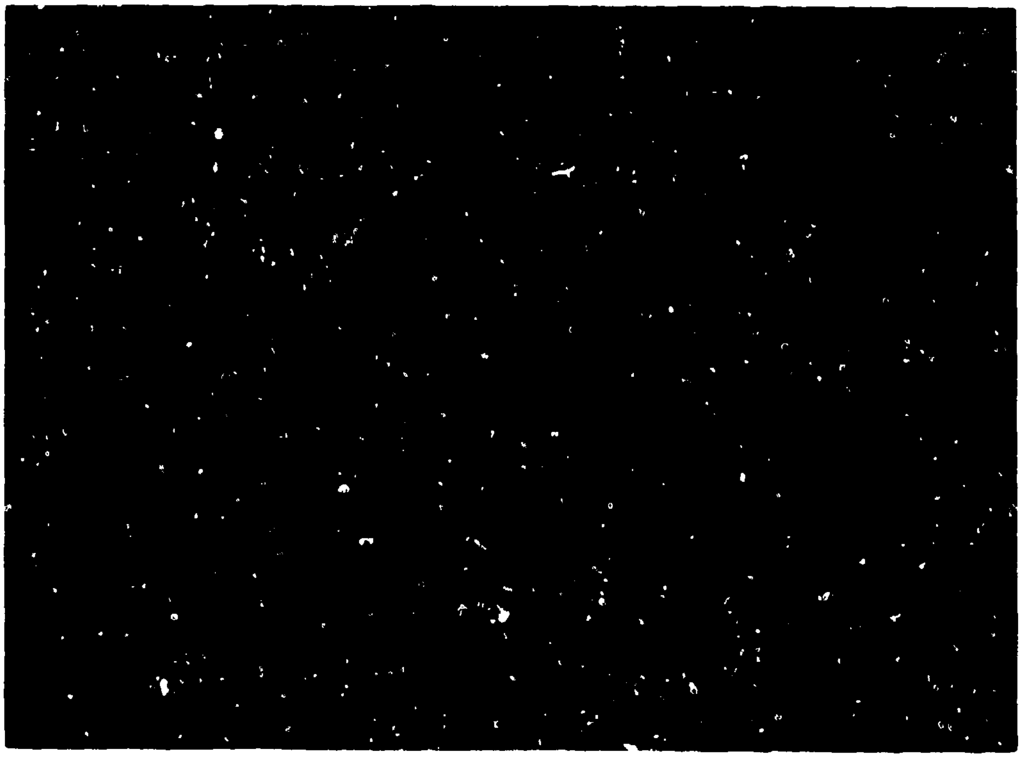

Figure 3: Height Map

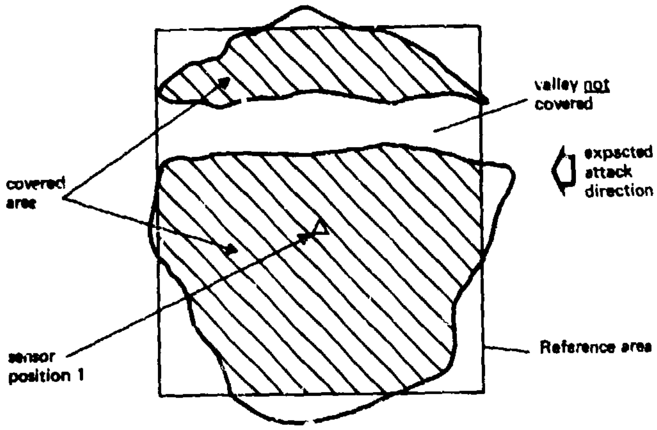

Fig. 4: Coverage Example 1
High coverage percentage, but insecure position

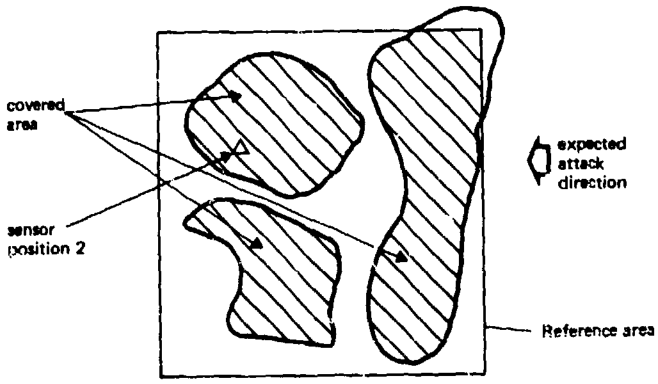

Fig. 5: Coverage Example 2
Lower coverage percentage, but secure position

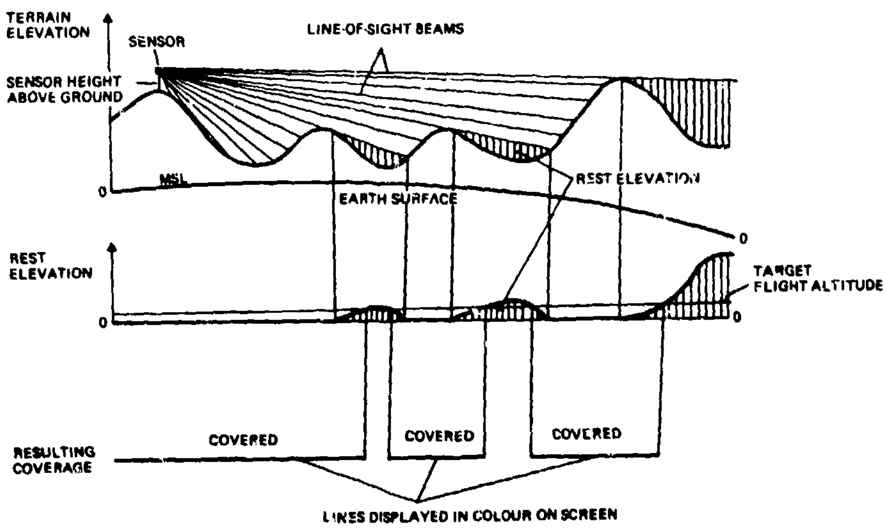

Fig. 6: Computation of the Rest Elevation

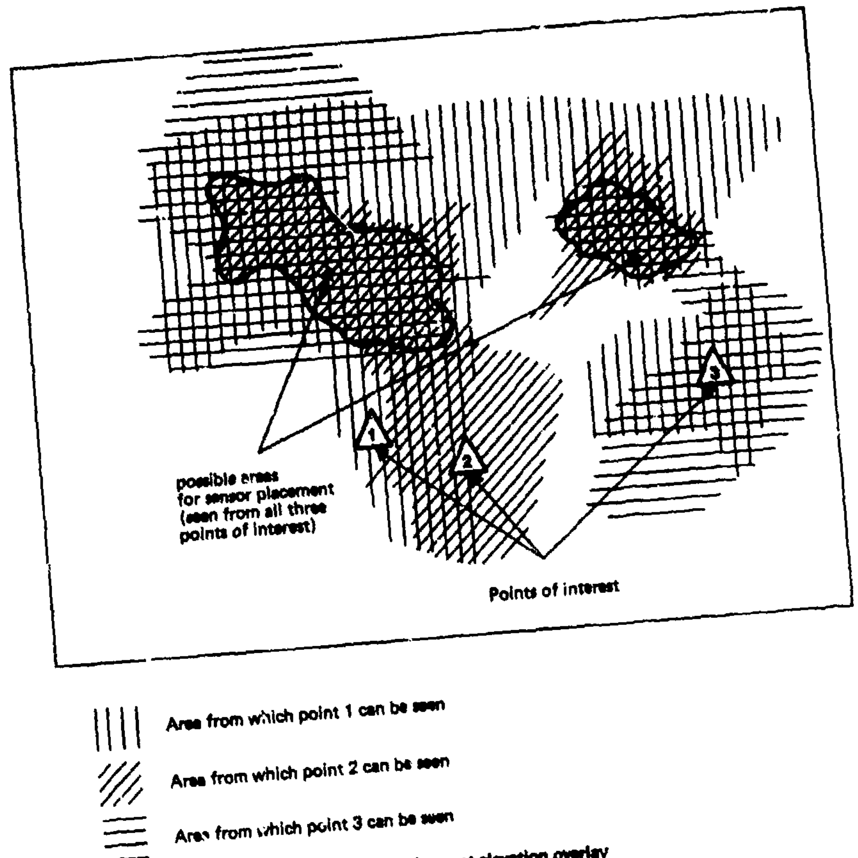

Figure 7: Reverse view rest elevation overlay

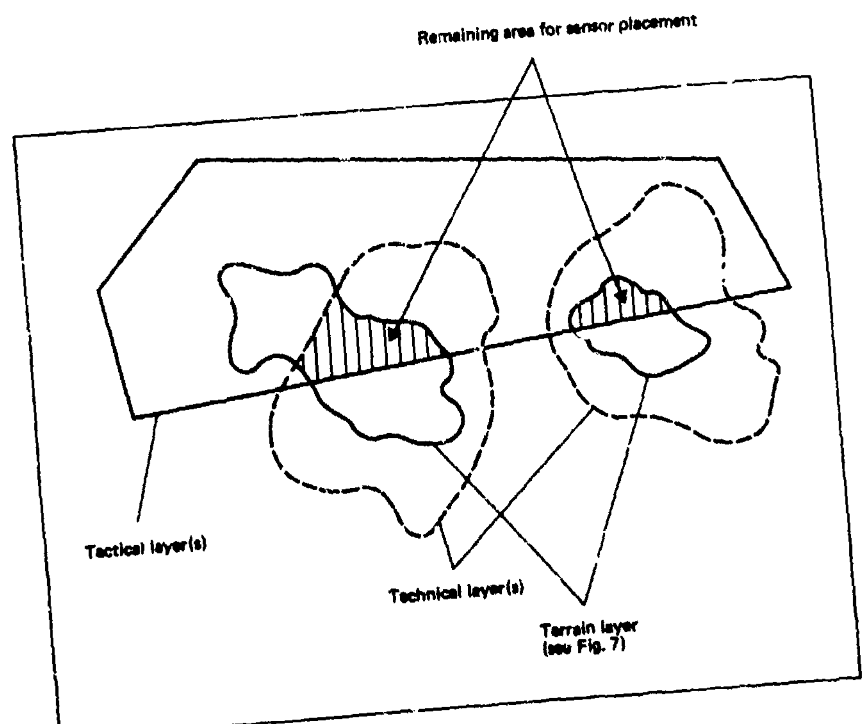

Figure 8: Intersection of Layers

DISCUSSION

W.E. Howell, USA

How long does it take the computer to produce the results shown in the example?

W. Rath

15 minutes computation time on a VAX 11/750 for all shown examples together. An optimization session including all user input would last about half an hour. The computation time decreases considerably if the number of pixels is reduced.

G.A. Ward, UK

Did you have an electronic display output as well as hard copy?
What was the resolution of the raster display?

W. Rath

The output is on a colour graphics terminal from which a colour hard copy can be made.
640 x 480 pixels.

E.M. Dowlen, UK

How far was culture (trees etc.) included in the coverage diagrams shown?

W. Rath

No culture data were available for the examples shown, but the tool is capable of using culture information, e.g. for radar clutter evaluation.

AD-P005 439

An Integrated Aircraft Navigation and Display System Utilising an On-Board Composite Data Base.

by

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Summary

It is likely that future aircraft will contain a central data base containing feature details, ground elevation, low flying obstruction data, intelligence and mission data. Recent advances in technology have made it possible to implement such a data base within an aircraft.

The existence of a central data base facilitates many new functions for both low level ground attack and air defence aircraft. These functions include: improved moving map displays, precision navigation systems, covert radar shadowing, surface to air missile site intervisibility, and perspective terrain displays for use in adverse visibility conditions.

The integration of such a system is currently being finalised and forms part of an on going flight trials program in fixed wing jet aircraft.

(1) Introduction

As a result of recent advances in technology it is now possible to create and utilise very large digital data bases. A point has now been reached where it is possible to incorporate a large data base within an aircraft avionics system to support additional navigation, display and mission functions.

Existing electromechanical navigation functions such as moving map displays and inertial navigation systems could be improved or replaced by avionics subsystems which access the database in real time. Furthermore new facilities, not previously possible, may be incorporated into the system to provide greatly enhanced operational capability.

This paper details the work currently being performed at GEC Avionics, Rochester UK, in producing an integrated aircraft avionics navigation system which could result in a single line replaceable unit. This unit fulfills the functions of a Head Down Display Color Map Generator with covert Radar shadowing and SAM site intervisibility, Terrain Referenced Navigation, and Terrain Following. The system is currently being proved in aircraft flight trials programmes in both the USA and UK. The programmes commenced the initial flight trial phases in fast jet operation in April 1986 and the full integration of all systems functions is planned for late '86 and early '87.

(2) The Central Data Base

It is envisaged that the aircraft of the future will have a large digital central data store readily accessible by the avionic sub-systems. Such a store in an advanced attack aircraft is likely to contain the following information:

- o Feature details (eg. roads, rivers, forests etc.)
- o Ground elevation profiles (eg. Digital Land Mass System. Digital Terrain Elevation Digital Data [DLMS DTED] or contours)
- o An obstruction overlay for low flying.
- o Intelligence data (eg enemy positions, Forward Edge of Battle Area [FEBA], Surface to Air Missiles [SAM] data).
- o Mission data (eg. waypoints, routing details, Initial Point [I/P]).

Great effort is being put into the realisation of such a central store; in particular the compilation of the various coded digital information blocks, the codification into suitable compressed formats, and in the development of the airborne memory medium such as laser disk technology and hybridised solid state semi-conductor memory devices. Suffice it to state that the work conducted to date has shown that a central airborne database giving a more than adequate aircraft operational coverage can be acheived.

(3) The Moving Map

A number of suppliers have developed a two dimensional CRT aircraft cockpit digital moving map display. It is possible to display in real time an exact replication of the standard aeronautical charts at various scales by the interrogation and manipulation of the central data base. These can be presented in either North orientated or Track orientated forms relative to aircraft present position. In addition a range of mission and intelligence overlay data can be superimposed on the map by additional symbol generation. Moreover, the colours utilised by the displayed map can be either manually or automatically selected according to the prevalent ambient lighting conditions, so that an ergonomically compatible map display can be viewed whatever the background lighting conditions, at night, or with the operator wearing night vision goggles. Since both knowledge of the aircraft altitude and the surrounding terrain can be supplied to the map display sub system it is possible to include further modes of operation over and above those currently possible with electro mechanical film based systems. These modes are:-

- Flexibility in altitude shading. An example of this could be that all altitude bands above the present aircraft altitude can be coloured shades of red and below current altitude in shades of green.

- The two dimensional display could be enhanced to give an apparent three dimensional map effect by the addition of sun angle shading. This has the effect of highlighting the topographical features such as hill ranges and river valleys.

- The database can be configured to organise the culture data files so that individual feature files (or groups thereof) can be displayed or decluttered in accordance with operational requirements. An example of this would be the removal of place names and minor roads when tracking a particularly strong topographical feature such as a river valley.

(4) Terrain Referenced Navigation and Terrain Following

By comparing a short duration of actual recorded heights overflown using existing airplane radio altimeter instrumentation with the relevant area or stored elevation data base it is possible to continuously update the aircraft present position continuously with a Kalman Filter. Various leading avionic and aircraft suppliers are conducting work in this field. GEC Avionics have been active in this area for the last seven years and have conducted a series of aircraft trials in the United Kingdom under the auspices of the Royal Aircraft Establishment, Farnborough. The results obtained have been highly satisfactory. From a precise knowledge of the terrain profile with respect to the aircraft position and flight parameters it is possible to derive vertical steering cues for manual terrain following or indeed to output the control commands to an Automatic Flight Control System. In addition, with the planned mission waypoints previously loaded into the navigation system either manual or automatic waypoint steering is possible.

In this paper it is not necessary to re-iterate the theory and methodology of these techniques since they have been discussed and presented to AGARD (1),(2),(3) on previous occasions.

However the very accurate knowledge of aircraft present position obtained by Terrain Referenced Navigation techniques together with the associated map and terrain data-base enables the implementation of further integrated aircraft navigation and display system functions, some of the more important of which are outlined in the following sections of this paper.

(5) Line of Sight Obscuration

If the aircraft present position is known (i.e. the latitude, longitude and height above ground level), the visibility or otherwise of any point on the ground may be determined. In the computation divergent lines of sight from the aircraft position are calculated, and systematically scanned from the aircraft position outwards, with the terrain data base being interrogated for all ground lying in the vertical plane of the line of sight. The calculation determines the visibility or otherwise of all points in that scan. A complete "radar scan" using divergent rays leads to the build-up of an entire ground visibility/obscuration picture for all terrain about the aircraft position. The resultant display produced in real-time from the digital data base is an accurate representation of a (terrain only) radar trace/shadow display but has the advantages of being completely covert. The advent of an accurate feature/culture data base in conjunction with the terrain data base will enable a true synthetic radar representation to be generated in real time (50Hz/60Hz) in a similar manner.

(6) Surface to Air Missile Site Intervisibility

At present the danger zones about a SAM site are highlighted on existing maps by concentric circles within which aircraft at known heights could be detected and within which it is obviously dangerous to venture. Techniques have been developed that are very similar to the line of sight obscuration just described but which take the position of the missile site as the origin. These generate a real time display showing those areas within the theoretical coverage of the missile site where the aircraft can safely fly at its current height above ground level since it will be masked from the missile site by intervening terrain and thus not detected.

(7) Landscape Imagery

From any three dimensional database it is possible to generate a synthetic image of the view from any given position and viewing angle. If the aircraft parameters (ie. position, height, pitch, roll and heading) are known accurately it is possible to generate a perspective image exactly corresponding to the actual view from the cockpit by using the terrain elevation database.
Such a synthetic image could prove invaluable, displayed on the Head Up Display one to one with the real world, during low level fight if the pilot temporarily lost sight of his ground references, for instance in adverse viewing conditions such sporadic low cloud. However the synthetic image is most useful in augmenting the display of the outside world derived from other aircraft sensors such as the Forward Looking Infra Red (FLIR). The resultant composite display can be viewed by the pilot head-up or head-down.

Previously the task of generating such a synthetic image in real time has been limited to large computer based aircraft simulators since the computational tasks, taking into account the real time rapid movements involved, have been beyond the scope of on-board airplane equipment. However, recent developments in microprocessor hardware, and a fresh approach to the necessary display algorithms have permitted the design of an appropriate real-time display as a self-contained part of an existing head-up display electronic unit or as part of an integrated navigatation and display system. This design results in a display capability which exhibits the required ergonomic characteristics suitable for mixing with the FLIR video onto a Head-Up Display.

(8) Air Defence Applications

The three dimensional calculations mentioned earlier may be used in two other modes, both of which are displayed head-down. Both of these modes have applications for air defence fighters on Combat Air Patrol (CAP) at medium heights (1000m to 5000m) using the look-down, shoot-down technique with modern missiles such as AMRAAM or Skyflash.

- 'Desk Top Mode' - A long range oblique view of an area of terrain which may be used for the presentation of the overall situation from the fighter's eye view. This mode is attractive for the 3 dimensional display of JTIDS information etc.

- 'Sun Angle Mode' - A plan view of the terrain elevation with shading showing shadows cast by an illuminating source such as the sun or a radar. It will allow pilots:-

  i) to choose optimum CAP altitude to minimise terrain obscuration.

  ii) to detect areas of inadequate cover, or short range detection, if constrained in height.

  iii) to avoid firing missiles which could lose the target through terrain obscuration after being launched.

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A J M Henly, A J K Clarke, Guidance System Division, GEC Avionics.

DISCUSSION

W. Rath, Germany
Which is the storage size available on board for terrain data?
How many maps can be stored in that storage?

M.L. Busbridge
Present system is about 8 MBytes for trials use only. Projected production systems requirement is for 300 MBytes to store approximately 1000 x 1000 nautical miles at 250,000:1, 500,000:1 and 1 Million:1. This will consist of either up to 10 PCB Card Modules of Hybridised EPROM or laser disk storage.
The Map Data will be stored in a composite database whose topographical features are held and read in parallel to the Terrain Elevation database.

J. Whalley, UK
To what extent is the data that you use standardised?

M.L. Busbridge
The elevation data used is the DLMS DTED (Digital Lane Mass Survey Digital Terrain Elevation Data). The topographical data is not yet standardised in that insufficient coverage exists in a digital form. Various manufacturers are digitising sufficient coverage for flight trials areas. This data is of course derived from standard aeronautical charts.

G.A. Ward, UK
Can you say why the maps you digitised still carry features unnecessary for flying tasks, e.g. place names, etc.

M.L. Busbridge
At present no definitive airborne requirements exist for those features which are necessary for both low flying and helicopter use. GEC Avionics are taking the approach of digitising each of the individual feature or "IN[illegible] [illegible]anes" which go to make up the total printed colour map (these number from 20 to 30 sheets for [illegible] map sheet). By digitising, collating and storing these separately we are, as a result of trials, able to vary at will the various combinations required for the various stages of flight. The objective is to determine which features or combination of features are necessary and have these as quickly selected pilot options. (A slide illustrating this function will be shown in Paper 32).

B. Stieler, Germany
In connection with TERCOM navigation, the terrain following flight (TF flight) can be carried out without the use of the TF radar. Could the author give an idea of what safety altitude he recommends to the pilot using this "synthetic" TF radar.

M.L. Busbridge
It is not intended to eliminate the use of real radar, but to limit its continuous transmission, perhaps to a burst every 10, 20 or 30 secs. dependent on the degree of confidence obtained by comparison with the TF synthetic image to a) the real world, and b) the "synthetic" E scope with the "real" E scope ski slopes, together with the various unspecified scanners, and the confidence in the DLMS DTED database.

C. Zappulla
In the conventional map there is an error in the height indications and it is reported on the map. As we intend to use "digit map" for TF navigation, what is the amount of error in "height" computation in this map.

M.L. Busbridge
This is dependent on the accuracy of the DLMS DTED database. A greater accuracy than the Level 1 is required. We have demonstrated that 3 metre errors in the database are acceptable for TF at 50 m AGL.

J. Davies, UK
Why was blue chosen to indicate a hazard region rather that the more traditionally used red indicator?

M.L. Busbridge
We did not like the look of red. However, any colour can be selected as a result of Trials and Ergonomic studies as the colour palette is fully programmable.

R. Guiot, France
Les [illegible]octets que vous avez mentionné couvrent-ils le trajet prevu pour la mission ou permettent-ils des deroutements importants.

M.L. Busbridge
The 8Mbytes covers 2 off standard 500,00:1 Aeronautical Charts + DLMS DTED Data for the same area. This gives a minimum flight path of 40 mins which is sufficient for trials use. The proposed production system is 300Mbytes which gives 1000 x 1000 nmi.

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14. Abstract

The pace and complexity of modern air warfare are reaching the point where advanced computer aids are becoming essential to assist the aircrew in the aircraft and the commander on the ground in performing functions that hitherto had been considered to be their prerogative. Computers are already used extensively in the operation and control of specific types of equipment, such as advanced weapon systems, surveillance radars, electronic warfare and communications systems. However, in the broader context there are still many areas which rely heavily on human decision making and where the use of computers will have considerable impact in the future. The increasing use of Artificial Intelligence (AI) techniques, including Intelligent Knowledge Based Systems (IKBS) and Expert Systems will at one extreme allow decision making to be increasingly automated or controlled by non-expert personnel, and at the other extreme greatly extend the capabilities of military commanders by presenting information in a timely manner and by making rapid assessment of alternative strategies. The successful application of computers should provide improved effectiveness, flexibility and reliability of both men and equipment resulting in a saving of resources and personnel.

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